DISSERTATION

Efficiency potential in private sector in ADRES

(Autonomous Decentralized Renewable Energy System)

ausgeführt zum Zwecke der Erlangung des akademischen Grades
eines Doktors der technischen Wissenschaften

unter der Leitung von

Em.O.Univ.Prof. Dipl.-Ing. Dr.-Ing Günther BRAUNER
und
Univ.-Prof. Dipl.-Ing. Dr.techn. Lothar FICKERT

eingereicht an der Technischen Universität Wien
Fakultät für Elektrotechnik und Informationstechnik

von

M.Sc. Sara GHAEMI
Löhrgasse 10/16,1150 Wien
Matr.Nr.: 0726370

Wien, im Mai 2011

Abstract

Over the past several years, European energy target "20-20-20 until 2020" caused enormous uptake of renewable energy resources especially micro generations in the production of electricity. Decentralized and non-dispatchable nature of generated electricity from renewable resources rises up new challenges in security, energy balance and frequency regulation of electricity grid specifically micro grids. In order to overcome the emerged challenges, energy demand on the top of it domestic energy consumption has drawn lots of attraction among last years. In this regard, energy efficiency (EE) is the first step in order to reduce the energy demand and consequently decrease the emission of CO_2, along with European energy target. On the other hand, demand frequency response (DFR) plays a significant role in making the frequency of the electricity grid balanced.

In this study, potential of energy efficiency in the domestic sector has been investigated through conducted survey in Austria. Result of the investigations reveals that only by replacing old white goods including TV with their best available counterpart in the market in 2020, almost 2.6 TWh energy will be saved in comparison with 2008. Taking all available energy directives and action plans in the Austrian domestic sector into account, leads to save in average 35% of annual energy consumption in individual households.

On the other hand, a daily load profile of individual households has been simulated via a stochastic Markov chain model. Results show that considering the demand as virtual power generation in micro grids, enables the power system to be provided with spinning reserves through consumption. Dispatching the demand makes up for uncontrollable produced electricity from micro generations in micro grids.

Kurzfassung

In den vergangenen Jahren hat das europäische Energiepaket mit den "20-20-20"-Zielen eine enorme Verbreitung von erneuerbaren Energien insbesondere im Bereich der dezentralen Stromerzeugung verursacht. Die dezentrale und fluktuierende Natur des erzeugten Stroms aus erneuerbaren Quellen bringt neue Herausforderungen in den Bereichen Sicherheit, Energiebilanz und Frequenzregelung von Stromnetzen (speziell Mikrogrids) mit sich. Diese Herausforderungen werden zusätzlich durch einen steigenden Energiebedarf, vor allem im Haushaltsbereich, überlagert. In dieser Hinsicht ist die Energieeffizienz (EE) der erste Schritt, um den Energiebedarf und somit die CO2-Emissionen zu reduzieren. Dies soll die Zielerreichung des EU-Energiepakets ermöglichen. Zur Stabilisierung der Netzfrequenz spielt Frequenz Demand-Response (DFR) eine bedeutende Rolle. Entsprechend wird in dieser Studie das Potenzial der Energieeffizienz im Haushaltsbereich in Österreich mit Hilfe von durchgeführten Umfragen untersucht.

Ergebnisse der Untersuchungen zeigen, dass nur durch den Austausch alter weißer Ware inklusive TV mit ihrem besten verfügbaren Gegenstück auf dem Markt im Jahr 2020 knapp 2,6 TWh Energie im Vergleich zu 2008 eingespart werden kann. Berücksichtigt man alle verfügbaren Energie-Richtlinien und Aktionspläne im österreichischen Haushaltssektor, können imMittel 35% des jährlichen Energieverbrauchs in Privathaushalten eingespart werden. Zusätzlich wird in der Arbeit der tägliche Lastgang der einzelnen Haushalte über ein stochastisches Markov-Chain-Modell simuliert. Die Ergebnisse zeigen, dass unter Berücksichtigung der Nachfrage als virtuelle Stromerzeugung in Mikronetzen, diese dem Netz als zusätzliche Regelungskapazität zur Verfügung steht. Dispatching der Nachfrage kann somit die nichtkontrollierbare Erzeugung von Strom aus dezentaler Mikroerzeugung in den Mikro-Netzen ausgleichen.

I dedicate this thesis to

my family

for their constant support and unconditional love.

I love you all dearly.

Acknowledgments

My last but not least task is to acknowledge all those people who have contributed to the work described in this thesis.

First and foremost, I would like to thank Professor Guenther Brauner for supporting me during these past three years. Without his support, accomplishing this work would not have been possible. I am also very grateful to Professor Lothar Fickert for reading my thesis and offering scientific advices and suggestions. My special thanks to Professor Luiz lopes of Concordia University, for his warm welcome to his working group "power electronics and energy research" and his valuable regular discussions in order to solve problems and presenting new ideas.

My research required the support of many electricity utilities in Austria. I am grateful to all of the people especially my Colleague Andreas Abart who not only provided required data but also valuable discussions about the subject. My colleagues in both EA and EEG groups provided me a friendly and cooperative atmosphere and patiently helped me improving my German language, thank you all.

There are many people who were interviewed for this work and others attended in measurement champagne. I want to express my gratitude to all these people, for their willingness in contributing to a scientific work and their patience in answering asked questions.

I appreciate my friends who helped me by reading and revising the thesis.

Finally, I would like to thank my family. Thanks for supporting me during my studies and urging me on. Mom and Dad, you are wonderful parents and wonderful friends. Sajjad, I could not ask for a better brother and friend. All of your continued support and encouraging after moving to Austria is deeply appreciated. Thanks for making me finish this work.

To all of you, thanks for always being there for me.

Nomenclature

E_{annual}	Annual energy consumption
$P_{min,u}$	Power consumption in minute u
E_{wtw}	Average energy consumption for weekday in winter
E_{wew}	Average energy consumption for weekend in winter
E_{wts}	Average energy consumption for weekday in summer
E_{wes}	Average energy consumption for weekend in summer
$n_k(t)$	Total number of changes from state k in time t
$n_{k,k+1}(t)$	Total number of transitions between state k and k+1 in time t
$P_{k,k+1}(t)$	Probability of changing the state from k to k+1 in time t

Abbreviations

EE	Energy efficiency
DFR	Demand frequency response
DSM	Demand side management
ADRES	Autonomous Decentralized Renewable Energy System
DR	Demand response
FIT	Feed in tariff
SF	Single fulltime family
CF	Couple fulltime family
SR	Single retired family
CR	Couple retired family
FF	Family fulltime
F	Family with one parent at home
FR	Family with retired member
EPA	Environment protection agency
wdw	Weekday in winter
wew	Weekend in winter
wds	Weekday in summer
wes	Weekend in summer
HH	Household
SLP	Standard load profile
FIFS	first in first serve
EU	European union
H0	Household standard load profile
SOC	Sate of charge

CONTENTS

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1. Introduction

Nowadays growth of electricity consumption (see [1] and [2]), worldwide finite deposits of fossil fuels to cover future demand (see [3]), increasing CO_2 emission making the environment polluted (see [4]) and lethal hazard of nuclear power plants in emergency and even normal operation mode (see [5]), cause more research in the field of renewable energy sources to provide enough energy for end users.

On the other hand, continued growth in energy consumption (see [6]) needs more energy production in the generation side. Since energy extracted from installed renewable units does not cover the growing demand yet, the amount of greenhouse gas emission and health/environmental risks of operating nuclear power plants will also increase consequently.

In this regard, due to the European energy target "20-20-20" [2], member states committed to reduce their primary energy use, increase energy consumption from renewable energies and decrease the CO_2 emission below 1990 level by 20% until 2020 [8]. Among all member states, Austria has been assigned a target of 34% increase in share of renewable energy sources and 16% decrease in amount greenhouse gas emission in non-trading sectors [9].

Uptake integration of renewable energy supplies into the public energy grid rises up new challenges. Intermittent and non-dispatchable nature of renewable resources makes some difficulties particularly in energy balancing of the electricity grid.

Unstable power flows in dominated renewable supply system may obstruct management of voltage and frequency of the grid. Since direct storage of electricity in the same form is not possible, either energy should be produced when it is needed or energy demand should be scheduled, as the generation is available.

Among all measures, in order to achieve EU 20-20-20 target, implementation of micro generation attracts more attention across EU member states. As a view point of European Union, Micro generation plays a unique role to solve the energy and environmental challenges in Europe [10].

In micro grids[1] that are dominated with renewable resources, inherent feature of supply does not let the generation side follow the demand side. For making frequency stable and increasing security of the grid, demand side could play an important role. Spinning reserves would be provided through demand response (DR) and matching load with time varying supply. Demand in the micro grid would act like virtual generation.

In this regard, traditional unidirectional power system will be not able to provide reliability and security for the power system.

To make the energy balance in such system, a new energy infrastructure, with an intelligent, flexible and bidirectional grid infrastructure, smart generation, and smart consumer with observing energy efficiency measures to reduce the energy demand would be essential.

[1] In this study, *micro grid* is a localized group of electricity generation, energy storage, and loads that operate autonomously and disconnected from traditional grid. Generation and loads in a micro grid are usually interconnected at low voltage.

Substantial uptake of micro generation within Europe needs more investigation in infrastructure, security and energy balancing in micro grids. Above all analyzing the domestic load profile in detail is highly required.

European domestic electricity consumption accounts for major proportion of the total electricity demand [11]. In Austria during the last decades, the amount of electricity demand increased continuously. The major driver is the residential sector with about 28% of the total energy consumption [12]. Since household demand accounts for significant proportions of total energy consumption in Austria (see Figure 1) as well as in Europe and because of variety of appliances with different power consumption and usage pattern also diversity of user behavior in the household sector, revival of interest has been came up in households energy demand and component of domestic load profile.

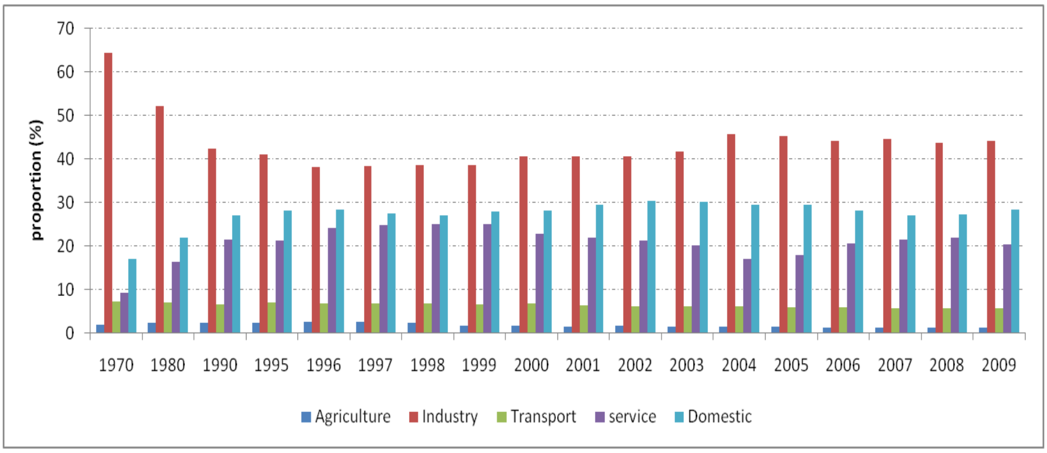


Figure 1: percentage of sector shares in total energy consumption in Austria

Micro generation is also highlighted specifically by underlining the importance of "buildings as power plants"[2] and emphasizing the benefits from the integration of sustainable energy technologies in household sector.

[2] Mass Market, www.microgenerationeuropean.eu

In order to comply with the EU energy target, Austrian national renewable energy action plan obliges a mandatory share of renewable energy in the building sector by 26% until 2020 [13].

Research and studies in the micro generation field reveals that visualizing the information of installed micro generation in the households, increases the energy awareness, which leads to conserve the behavioral effect, reduce the energy consumption by 20% from pre-micro generation levels [14]. In addition, user behavior in household would be significantly altered in order to reduce the energy consumption after installation of micro generation in the building.

Since micro generation encourages energy consciousness behavior, it would help the member states reducing the amount of energy consumption through efficient user behavior as well as increasing the share of renewable energies in the generation side.

In this regard, Austrian energy efficiency action plans addresses additional subsidies for use of renewable energy resources in the dwelling sector in order to improve the energy efficiency of the buildings [15].

In order to make Austria independent from fossil fuel energy resources the only possibility is making the household energy demand as efficient as it is possible. Deploying energy efficiency tools will help to reach the aim.

Energy efficiency can be discussed from two points of view:

- Energy efficiency of household devices
- Efficient use of appliances and enhanced user behavior

Using these energy efficiency tools, not only help to reduce the household electricity demand but also let the energy needed by electric cars covering in the autonomous decentralized grid (see [16]).

Widespread support of micro generation consequently micro grids in European countries especially Austria stresses the study of energy efficiency, user behavior in the household sector and energy/power balancing in the micro grid more than before.

On the other hand, the non-dispatchable nature of renewable units in micro grid, that is dominated with micro generation, cause emergence of new concept in making the energy/power of the grid balanced.

There are two ways of making the grid balanced:

- Like the existing system the load of total consumption is prognosticated and the capacity of generation must be conformed to the predicted load.
- Considering the generation limits, load would comply with the existing energy sources.

In the framework of autonomous decentralize renewable energy system demand should be adjusted with generation. The diversity of load demands at macro scale is such that there will always be an intermittent demand ideally matched to the power available from the renewable energy systems (see [17]). As the diversity of loads in household sector is more than in the other sectors, the focus of this study is on domestic buildings.

In order to match load shape to the power generated by local renewable energy systems, it is essential to identify the pattern of energy use in household to predict domestic load profiles. In this regard, the consumer behavior and household load profiles must be analyzed in details.

Because of stochastic inherent of electricity use in household and regarding the unpredictable behavior of the individual user's at home, it is always an important matter anticipating the load profile of the household sector for balancing the electricity network.

1.2. Goal of Dissertation

Due to the uptake of micro grids including micro generations and the necessities of demand side management (DSM) in order to make balance between fluctuated generation and domestic consumption, developing a dynamic load profile is compulsory. Developed load profiles not only should be able to describe the normal requirement in the unperturbed network operation by stochastic models, but also the pent-up demand for reductions or interruptions in energy supply.

Based on development of efficiency of household appliances (lighting, appliances, consumer electronics, etc.), technological measures must be applied to reduce households energy needs. Based on real time measurement of electricity demand of household appliances, dynamic modeling of electrical behavior of electricity customers is developed.

These dynamic models can be used together with surveys of the behavior of different users to get the synthetic modeling of load profiles. The dynamic load profiles should also take into account the behavior of restocking after interruption. Finally, the possibilities of the DSM in consideration of the potential, user acceptance and energy efficiency will be evaluated.

The main objectives of this study are listed as following:

- To conduct a survey to collect information about status of household devices, their energy class and domestic user behavior
- to analyze the user behavior, effect of energy labeling and standards of household devices on energy performance and energy/power usage pattern for make a balance in micro grids
- to run a measurement campaign for measuring the total energy consumption and possible individual household devices in high resolution

- to develop a method for predicting household's daily energy-consumption profile for planning and strategic design of renewable energy system for residential building
- to consider different DSM scenarios in an interrupted grid

1.3. Thesis Outline

Chapter 1 has presented a brief introduction to the concepts of micro generation, required energy efficiency (EE) measures and demand frequency response (DFR). Additionally, Chapter 1 summarizes the motivation for this work and presents a brief overview of this thesis. Published papers also have been listed.

Chapter 2 presents the relevant literature study and background information in the following order:

1- Energy efficiency
2- Demand side management

Chapter 3 describes the survey conducted among electricity customers and depicted the result of investigation on gathered data. Based on result of data assessing, a scenario of energy saving potential in 2020 has been developed. Average annual energy required in households with different sizes has been estimated and has been compared with national available data from Statistic Austria.

Chapter 4 presents measurement campaigns carried out in upper Austria. Based on designed databases, a stochastic Markov chain model is developed in order to simulate usage pattern of individual household appliances within a day. A bottom-up algorithm deployed to model domestic daily load profile. In order to validate the results, a domestic settlement has been defined and a simulation model has been used to simulate a load profile of a defined settlement, which is supplied with micro generation units. Finally, the results are compared to the scaled standard load profile for the settlement.

Chapter 5 represents application of demand side management based on demand frequency response.

Chapter 6 presents the conclusions of this thesis, and recommendations for future work. This is followed by bibliography.

1.4. Publications

1) Potential of reducing the electricity demand in private sector [18]
2) Dynamic Load Profile in ADRES project [19]
3) User behavior and patterns of electricity use for energy saving [20]
4) Stochastic model for household load profile [21]
5) ADRES@WORLD [22]
6) S.ghaemi, "Energy efficiency: The pathway toward a nuclear-free world", Submitted paper in e&i– elektrotechnik und nformationstechnik- journal
7) co-Author, *ADRES Autonomous Decentralized Regenerative Energy-Systems [23]*
8) co-Author, ADRES Concept – Micro grids in Österreich [24]

Chapter 2

Literature study

2.1. Literature Review

There are numerous studies that have been performed by number of researchers to investigate the potential of energy efficiency using different available methods. In order to estimate the potential of energy efficiency, energy consumption and related influencing factors has been assessed and results have been published in scientific papers.

Lutzenhiser in 1993 claimed that effect of micro social parameters on energy usage including variation in micro-level activities and difference in related functioning appliances, make the difference between levels of energy consumption in households (see [25]). Other similar studies indicated that between 26% and 36% of in-home energy use is due users behavior (see [26],[27],[28]).

Wood and Newborough in 2003 declared that there are three ways for reducing rate of energy consumption. Replacing the existing housing stock with low energy building, replacing the electric appliances with their efficient counterpart and promoting energy conscious behavior among end users, are tools for influencing the energy consumption in the various energy sectors. It is also claimed that through energy feedback via smart meters and energy consumption indicators, households achieve in average 15% reduction in their energy use (see [29]).

Houwelingen and Raaij approved famous Hawthorne effect in the energy monitoring. They showed that energy monitoring feedback is a promising approach to energy conservation. They compared two observed groups with cumulative daily and monthly feedback. Amount of energy saving in first group was significant as the result of Hawthorne effect (see [30]).

Latter in this regard, S.S.Van Dam et. al. In 2010 pointed out, the participants' awareness that their electricity consumption was being monitored during the initial trial might have contributed to the higher savings. The case study, which has been done in this research, confirmed the need for application of Hawthrone effect in energy monitoring (see [31]).

There are also various studies about development of domestic load profiles using available sources of data and application of bottom-up approach since 1980.

J.Broehl in 1981 presented an approach for forecasting the end-use energy consumption in hourly resolution. Aim of work was building detailed model to make analysis and exploration of different load management strategies possible. The models were using bottom-up approach to forecast the total energy consumption of different household devices in a region / settlement but not for individual households. It is obvious that the sum of corresponding demand for individual appliances in a region would be the total regional consumption of residential sector [32].

In 1985, Walker and Pokoski [33] constructed electric load profiles from individual appliance profiles. They introduced the concept of using "availability" and "proclivity" functions to predict whether someone is available at home and active to use energy and their tendency to use an appliance at any given time. These functions were applied to predict individual appliance events, which were then aggregated into a load profile. Simulated profiles were compared to real measured data. This preliminary modeling work was conducted for the purpose of predicting loads and load changes due to social and economic factors, in order for power generation planning.

A.Capasso in 1994 [34] developed the idea of Broehl in end-use load forecasting approach. Functions in Capasso's model were based on factors such as occupant availability, activities, human resources and appliance ownership. He used the gathered data trough time of use survey and household consumption survey to generate the schedule of availability of household's member at home and probability profile of home daily activities via Monte-Carlo method. Load profiles were simulated for each individual household in the hourly time interval using the synthesis procedure, which has involved aggregation of the contribution made by individual appliances to the household demand profile and aggregation of the various relevant household profiles to arrive at the demand shape of the entire area.

Y.Shimoda in 2004 simulated the household load profile considering the effect of type of household and dwelling on the energy consumption. In his model, effect of different day types and season on the different category of household appliances is assessable. There are two types of time resolutions in the model, energy use pattern and hot water supply have been simulated in 15 min. time interval and cooling and heating models are in one-hour time resolution [35].

Yao and Steemers (2004) created a simple method of predicting household electrical loads for the design of renewable energy systems in the UK. Their load prediction was based on detailed inputs including the number of occupants, occupied hours, the period when each appliance will be used, and the number of hours of use per day. Yao and Steemers' generator allows an appliance event to occur with equal probability at any time during a designated time period [36]

Similarly, Paatero and Lund (2005) created electrical profiles to examine demand side management strategies for Finland. However, they used a different bottom-up approach based on statistical consumption data, and not detailed occupant's behavior. Electrical data from hundreds of apartments in Finland formed the basis for the statistics used to fabricate these hourly demand profiles [37].

I.Richardson presented in 2008, a high-resolution domestic building occupancy model using Markov chain technique in order to simulate the energy demand. Later on, the occupancy patterns generated by this model were used in simulation of domestic energy demand model [38].

In 2010 I.Richardson presented a high resolution energy demand model using similar method like Capasso has been used but with higher resolution. The Time Use survey in this study has been gathered in 10 minutes resolution. Active occupants, their activity and related appliances to the activity has been defined based on the conducted survey [39].

D.G.Infield in 2007, presents the potential for Domestic Dynamic Demand-Side Management. In this paper, a simplified system model has been built to explore the impact of rescheduling of domestic activity and related electricity consumption on the load profile [40].
Later on, in 2008 V.Hamidi, F.Li and F. Robinson published a paper about effect of responsive demand in domestic sector. In this paper, the amount of dispatchable responsive demand from domestic sector with different load tariffs has been evaluated and the benefits of responsive demand in order to increase the security, reducing the emissions and production cost in an intermittent system has been presented [41].

Part one

Energy autonomy

Chapter 3

Energy efficiency potential

3.1. Introduction

Between 1951 and 2001, there was a decline in the average size of households in Austria, from 3.11 persons to 2.38. It continued to decline at a slower rate during the next decades falling to 2.29 in 2011. Prognosticated data from Statistic Austria (see Figure 2) shows continual decreasing trend until 2050 with 2.14 persons per household [42].

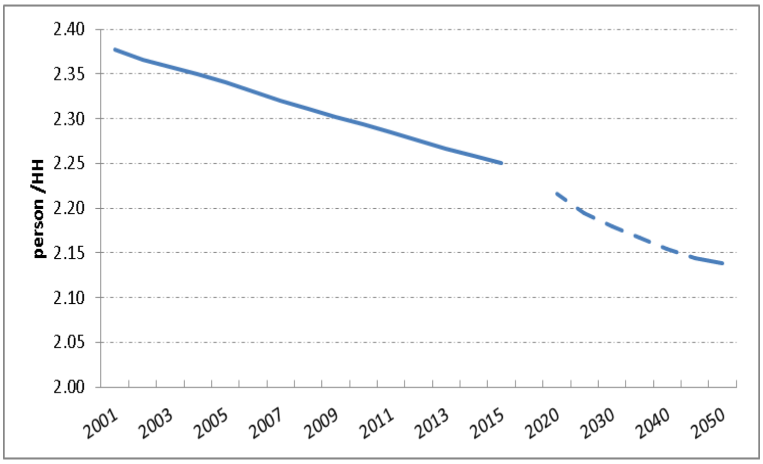


Figure 2: average number of persons in Austrian households

Since 1951, there have also been changes in the composition of households. In particular, these have included an increase in the proportion of single households. Between 1951 and 2001, the overall proportion of single households almost has doubled from 17.5% to 31.2% (see [43]).

Figure 3 depicted the proportion of different household's composition since 2001 to 2050. Same increasing rate in the composition of households in the next 40 years, leads to higher proportion of single households almost 40% in 2050 (see [44]).

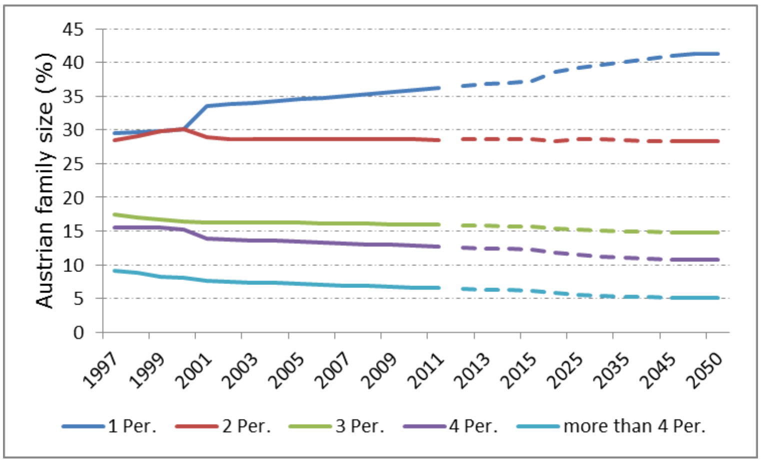


Figure 3: composition of households in Austria

Increasing number of single households in future leads to increase the number of household appliances per person and consequent electrical energy consumption as well. Despite applying energy labeling since 1994 to some household appliances like refrigerator, freezer, washing machine, dryer and dishwasher, annual domestic energy consumption has been increased (see Figure 4).

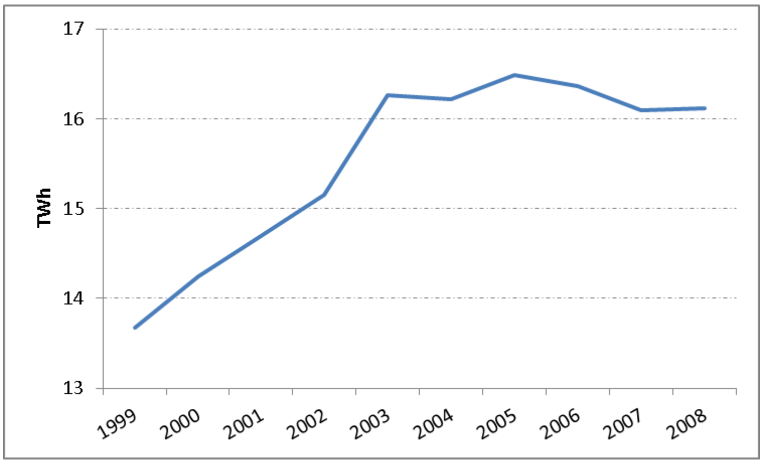


Figure 4: annual energy consumption in Austrian domestic sector

Increasing the size of household devices like refrigerator/ freezer and proliferation of electronic gadgets simultaneously with execution of energy labeling directives redeem the effect of efficient devices in the total consumption of households.

Continues growing in domestic energy consumption, which is 28% of the total energy consumption of Austria (see [45]), requires more energy on the generation side. Since energy extracted from installed renewable units does not cover the growing demand yet, the amount of greenhouse gas emission will also increase.

In this regard, efficiency of end-use devices and efficient use of household devices in order to decrease the annual energy consumption and consequently lower amount of CO_2 emission should be considered.

Involving the individual consumers or rather households in the renewable energy and energy efficiency action plans, in one hand cause contribution of citizens in reducing carbon footprint and increasing the motivation of energy consciousness. On the other hand, consumers will benefit from lower annual energy price via implementation of feed in tariffs (FIT) which is for example for building-integrated photovoltaic is about 38 Cent/kWh (5 kWp to 20 kWp) in Austria [46].

Importance of contribution of citizens in successfully achievement of "20-20-20" target motivated the precise study of household user behavior and potential of energy saving

In this thesis, household's electric appliances, their usage pattern, domestic load profile and influencing factors on shape and amount of load profile like appliances ownership level, demographic factors, household type and user behavior has been explored

Looking for required data in literature studies revealed no available data in proper size and shape. It is decided to gather the relevant data to this study through a survey among Austrian households.

3.2. Penetration of electrical appliances Survey in domestic households

As a contribution to gathering the data of household sectors energy consumption and its relevant component, Author conducted a consumer survey among Austrian electricity customers with the help of Austrian electricity utilities and under support of "ADRES Concept" a national project funded by FFG [3].

Major objectives of carried out survey were,

1- gathering demographic information, penetration level of electrical appliance in domestic sector
2- increasing understanding of user behavior and factors which are influencing it
3- obtaining data about saving potential in customers energy consumption and their flexibility in applying some demand side management programs

3.2.1. Questionnaire survey

For gathering the required data of electricity customers in Austria, a questionnaire was designed by Institute of energy systems and electrical drives in seven main sections [47].

Section I was asking about some General demographic information of the household like the number of children in two categories (under 14 and above 14 years old), number of retired persons, number of full and part

[3] ADRES Concept (Autonomous Decentralized Renewable Energy System) is a national project funded by FFG (research funding organization). Project started in 2007 and lasted three years. In "ADRES Concept" project, a Micro Grid, with the limited renewable generation were studied. The goal was to make a feasibility study, simulate and prepare for implementation of an autonomous decentralized renewable energy system.
Study has been done based on three main objectives, "Regenerative Generation ", "Efficient end-user" and "Smart Energy System". Project report has been submitted but has not published yet.

time job, type of building (Detached, semi-detached and apartment), its floor space (m²) and location of building (rural/urban)

Section II was about average function time of kitchen devices like microwave and frequency of their usage.

Section III gathered some information about size and age of white goods in the household.

Section IV was about cyclic devices like wash-machine and dishwasher, number of needed wash cycles per week in summer and winter.

Section V collected the data about Ownership level of electrical appliances that are used at home

Finally, the two last sections were about flexibility of customers in changing the time of use of some certain devices during a day and Interest of people to apply energy saving measures

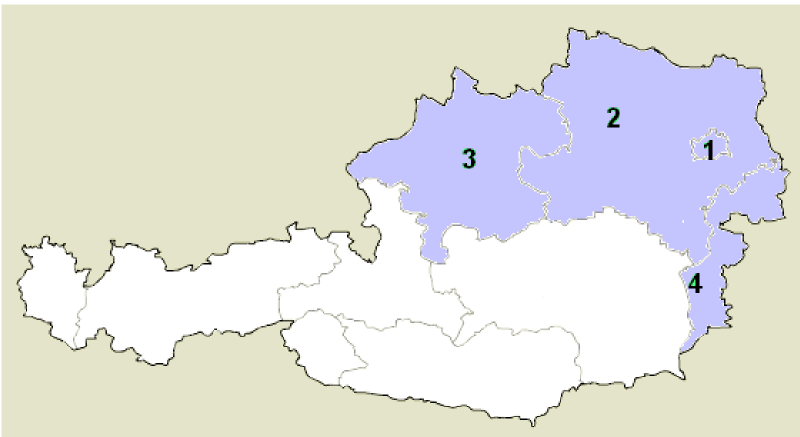


Figure 5: conducted survey in depicted Austrian provinces

Available literature surveys are including information like level of ownership and demographic of households but they are less concerned on the user behavior and DSM. Recently there are also many international studies [48], that have been done in this regard, but since cultural backgrounds, energy policy and peoples motivations are different from one country to another it is decided to go through the process of gathering the information of electricity customers in Austria.

The questionnaire required 15 minutes on average to fulfill. It was distributed among 20.000 Austrian electricity customers in four provinces (see Figure 5), Vienna, upper-Austria , lower-Austria and Burgenland between January and March 2008. As cost and accuracy are two main drivers in order to design a statistical sample, a trade-off between both parameters has been considered in order to get representative sample size. Since Austrian utilities cooperated in distributing the questionnaire among the electricity customers, regional stratification has been designed automatically regarding the territory of utilities.

Completed questionnaires were subsequently collected from customers through post anonymously and the responses have been analyzed. Average response rate of 20% was achieved.

Table 1: provincial sample response

		Population (2008)	distributed	Respond	Sampling fraction
Stratum 1	Vienna	1,674,909	5000	591	3 in 10000
Stratum 2	Lower Austria	1,596,538	6000	1868	1 in 1000
Stratum 3	Upper Austria	1,406,664	5000	542	4 in 10,000
Stratum 4	Burgenland	281,185	4000	831	3 in 1000
Primary sample	Austria (East)	4869296	20000	3832	8 in 10,000

Table 1, indicates that although the questionnaire has been distributed homogenously, the response and sampling fraction, which has been got back, seems heterogeneous. In this regard, it is decided to study and analyze the primary sample with fraction of 8 in 10.000 without splitting the sample to different territories.

Different geographical positions and their relevant possible changes in user behavior and consequently energy consumption has been ignored.

3.2.2. Methodology of data analyzing

After gathering the data via conducted survey which is from now on called ADRES survey and before start analyzing the data, sample characteristic including respondent's household size, ages, family type and annual energy consumption were compared with the corresponding national data available in statistic Austria.

Comparing the size of households in sample and data from statistic Austria [49] shows that except single families, sample is almost representative (see Figure 6). Sample's household-size has been more nationally representative if more single households had responded.

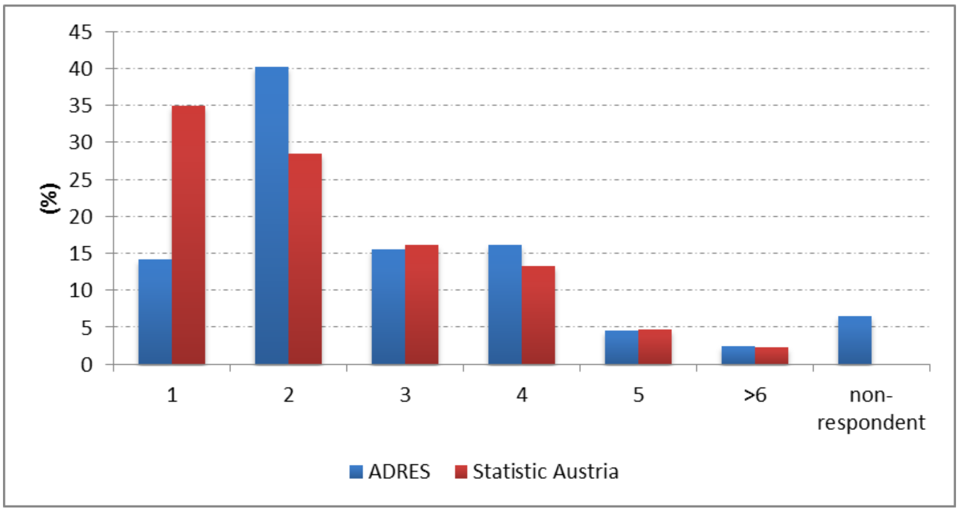


Figure 6: proportion of sample households according to household's size

Figure 7 and Figure 8 represent sample characteristics including respondent's number of children and floor space (m²) compared with the corresponding national data from statistic Austria respectively. Number of children in the national level is very well correlated to the distribution of data in sample.

As it is mentioned before, more attended single households would also lead to have more single houses and consequently more floor spaces under 90 m² and better representative sample with similar characteristics to Austrian statistical data.

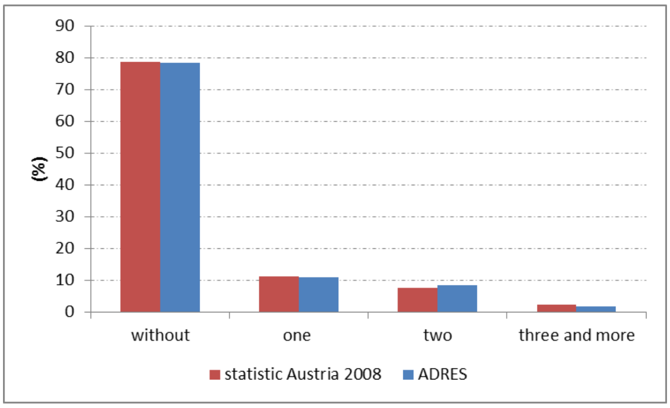


Figure 7: proportion of households with children less than 14 years old

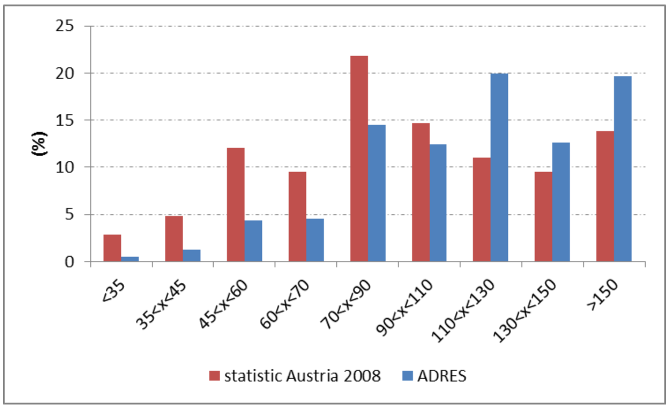


Figure 8: proportion of households with categorized living area(m^2)

Energy consumption is another measure to assess whether the sample is representative enough. Figure 9 & Figure 10 show the annual energy consumption of households according to different floor spaces and households size respectively.

There are some differences in the national average annual energy consumption and sample data, which is due to few numbers of attendants in the ADRES survey.

Presence of one household with extremely low- or high- energy consumption among ADRES sample is enough to alter the average value. In this regard using the median values is acting like a filter to remove the effect of extraordinary values from energy demand of the sample.

Right half of the both figures show the median of national values in compare with data from ADRES survey. As it is expected, the correlation between median of national and gathered data is more than the mean of national and gathered data.

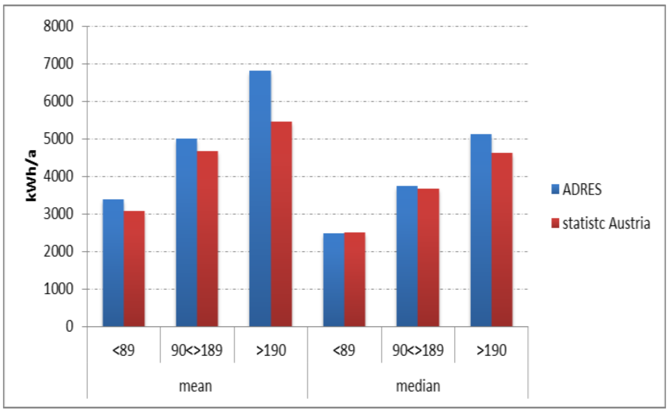


Figure 9: annual energy consumption according to floor space (m²)

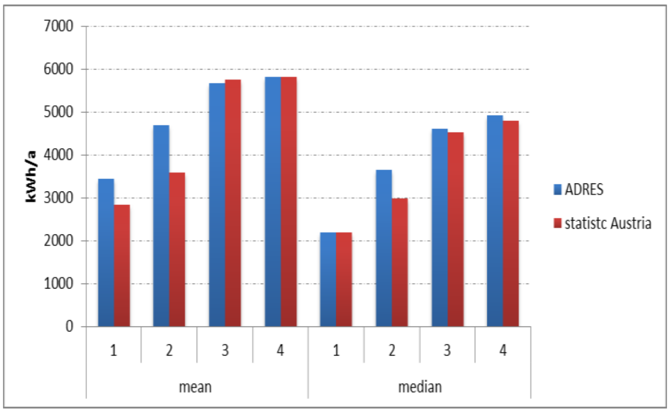


Figure 10: annual energy consumption according to households size

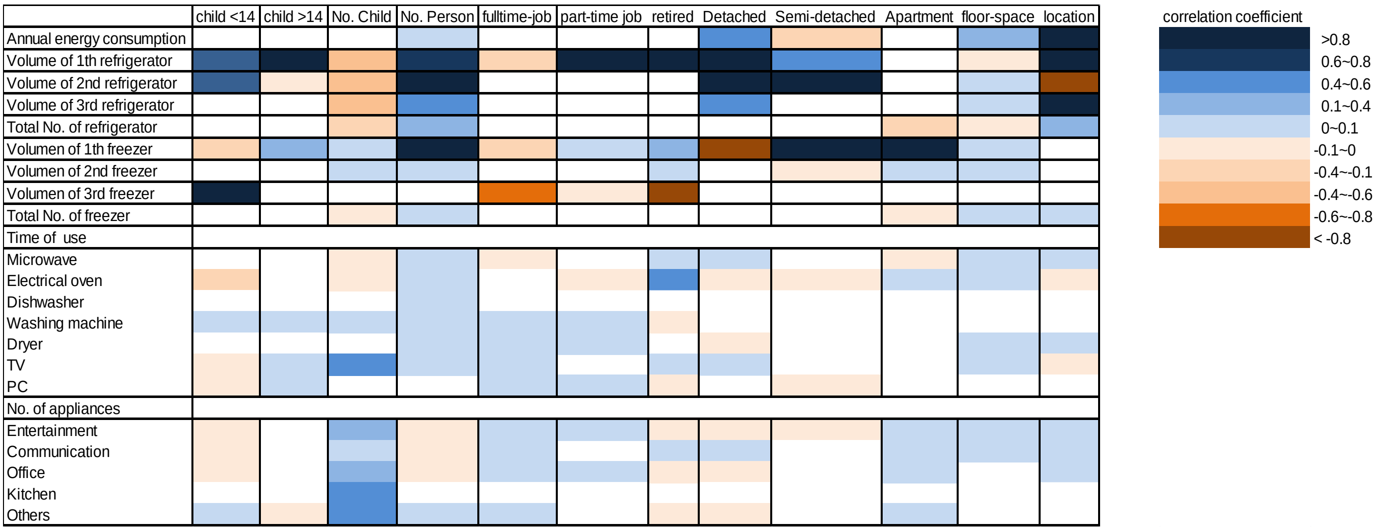
Analyze of data manifested nearly representative nature of gathered sample. Further study has been based on the extracted data from analyzing the sample.

For further data analysis, it is important to know which parameters influence the annual energy consumption and usage pattern of appliances. Households can be classified in different categories regarding the influencing factor.

Comprehensive set of data gathered through questionnaire has been analyzed in order to understand the influencing factors on user and usage behavior. Stepwise variable selection algorithm has been used to determine the criteria for data classification (see [49] to [55]). Table 2 indicates the correlation coefficient of stepwise variable selection analysis with spectrum of colors.

Result of study shows that age of children, household composition, occupancy pattern of house, type of building and living area are most important influencing parameters on the size of cooling devices, usage duration of kitchen devices like range and microwaves and number of electric devices in the household

Table 2: influence of various parameters on user behavior



Since in the settlement planning it is not possible to consider the age of occupants it is decided to make a classification upon independent factors like number of people and their occupancy pattern which is driven from type of job, full-time , part-time and retired.

Figure 11 shows influencing factors and different family categories based on the result of variables selection. Defined family category is the base of further analysis.

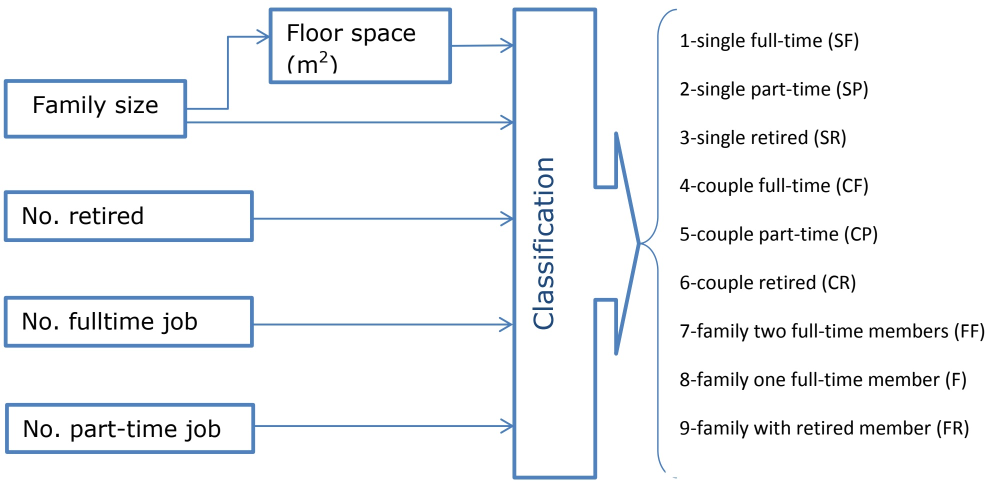


Figure 11: sample classification

Cross sectional analysis of ADRES survey data indicates that floor space is a function of number of family member so it is influencing the classification as a dependent factor (see Figure 12). The higher the size of household is the higher the floor space of the building. Another factor that is influencing the floor space is building location. Average floor space in urban area is lower than in rural area. Regarding lack of representative data in each category, the effect of this factor has been neglected in the study.

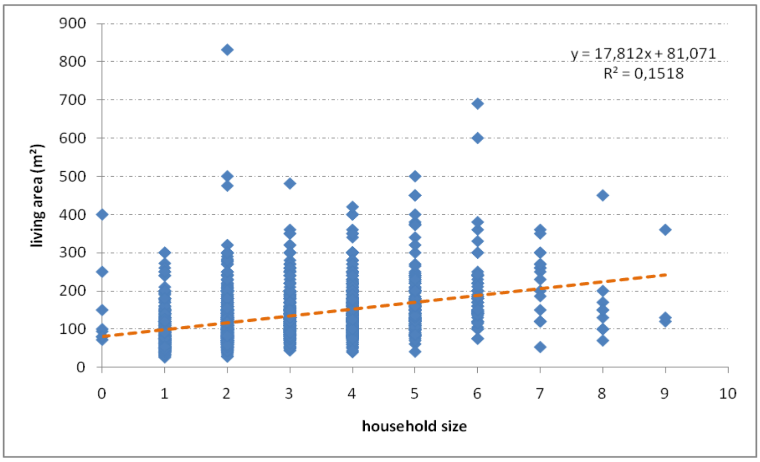


Figure 12: correlation between household size and living area (m²)

Almost 4000 fulfilled questionnaire revealed information about individual energy users within their households. The findings of the survey are reported under two main headings:

1- Penetration rate of households appliances and their usage pattern
2- Energy consumption and user behavior

3.3. Penetration of household appliances

Several questions were formulated to elicit penetration rate and frequency of use for available domestic appliances. From heating system to small household electronic devices were asked in the survey. In the following subsections the results of analyzing the conducted survey are presented. As long as there is a counterpart available with national data, the result of investigation has been validated.

3.3.1. Electric hot water and space heating

Result of survey shows that 47% of the households in ADRES sample use electric energy to make hot water. Water boiler, water heater and small hot water storage has been used in 29%, 8% and 7% of the households respectively.

Only 20% of the households use electricity for space heating. Five percent of it, is related to heat pumps. Other 80% use gas, oil, or district heating system. National statistical data shows the declining trend of using electric heating system since 2003. Instead, the increasing rate of heat pumps and solar heating system is considerable. Higher percentage of electric heaters in the sample cause higher energy consumption in comparison with data of statistic Austria (see Figure 13 & Figure 14).

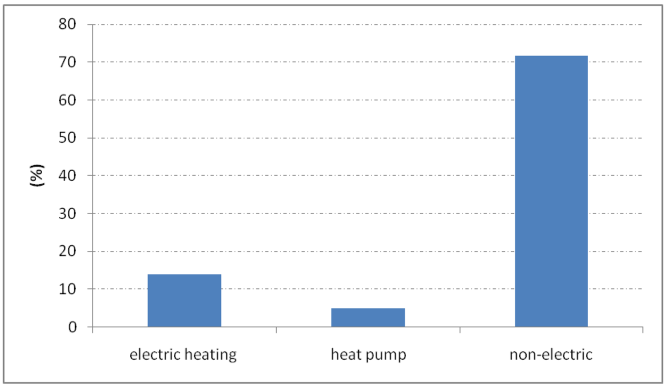


Figure 13: type of space heating system in sample households

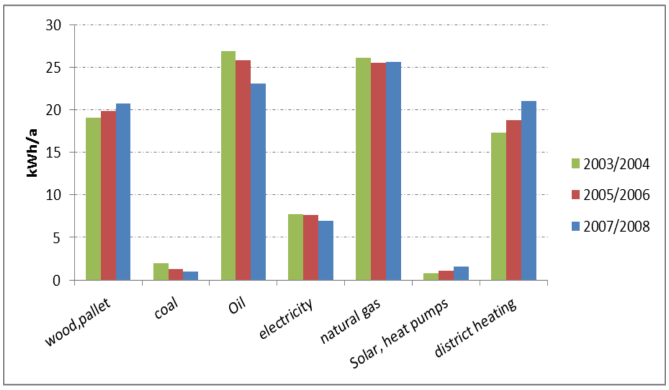


Figure 14: type of space heating system in Austria

In explored households, there is still no considerable amount of ventilation and air conditioning system. Excluding the missing data that is coming from the uncompleted questionnaires, 85% of the households have no electrical ventilation system (see Figure 15).

Increasing trend of average temperature on the earth since 1990 could lead the higher number of needed ventilation systems and air conditioners in future.

On the other hand increasing the trend of passive houses and their need to have circulated air for optimal cooling and heating system is another incentive to increase the number of ventilation system in households in future.

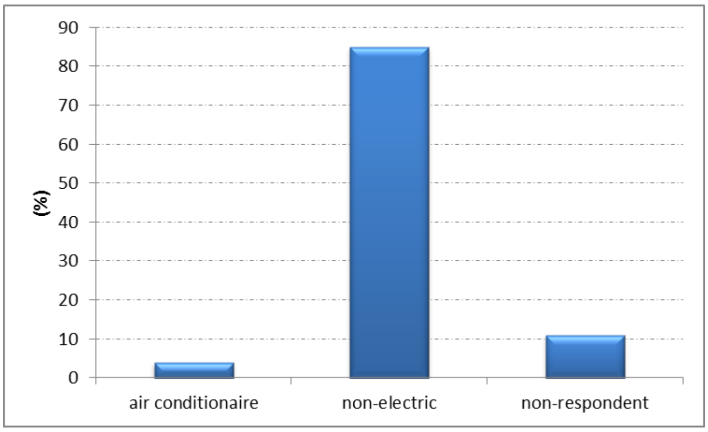


Figure 15: proportion of ventilation and air conditioner in sample households

3.3.2. Cooling devices

Refrigerator is one of the popular household devices that exist in all households. Not only all of the households have one refrigerator but also some households have multiple devices even three fridges per household. Figure 16 depicts almost 75% of the sample households have one refrigerator, 20% have two and 2% have three fridges. Result of data analysis shows that changing in life style cause to change the number of refrigerators.

For example when the people take retirement or are changing their job from full-time to part-time or when the number of adult members (>14 year old) increase the need to have a bigger fridge emerges. Regarding Table 2, the third refrigerator is slightly correlated to the selected variables. It can be explained, as the people do not throughout their old appliances because they are still in function. By changing the life style and emerge of new luxury refrigerators in the market the purchase of new devices starts but the old device would be put in cellar and might be still in use.

If people instead of adding another refrigerator for providing their demand of having bigger device, buy a new bigger device and through the

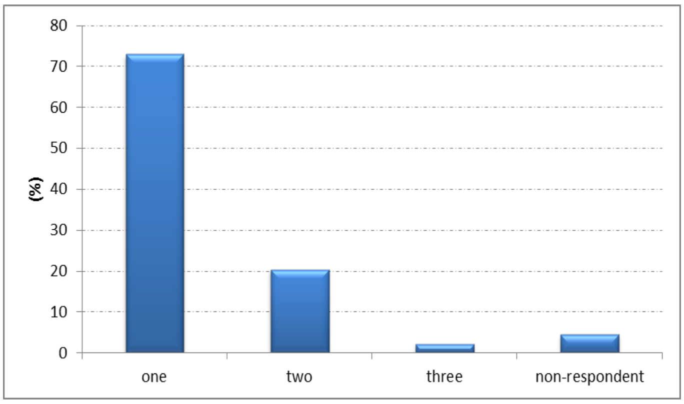


Figure 16: proportion of households with different number of refrigerators

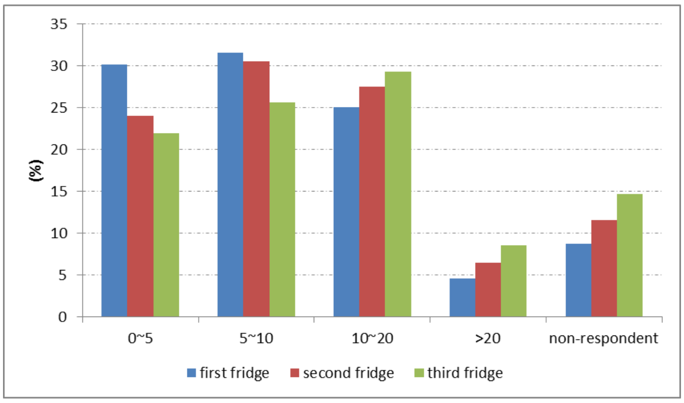


Figure 17: distribution of sample refrigerators in different age categories

old device away, energy waste through multiple device will be solved. In Figure 17 distributions of sample's refrigerators have been presented. Just 30% of the first fridges have been bought in last 5 years. 9% of the respondent didn't answer to the question. Including missing data in the category of devices older than 5 years, 70% of the refrigerators are older than 5 years. Regarding the sample data, average number of refrigerator per household is 1.2 units.

The same situation is valid for freezers (see Figure 18 & Figure 19). The average number of the freezers per household is 0.9 units. Just 25% of these freezers have been bought in last 5 years. Other 75% including the missing data are older than 5 years.

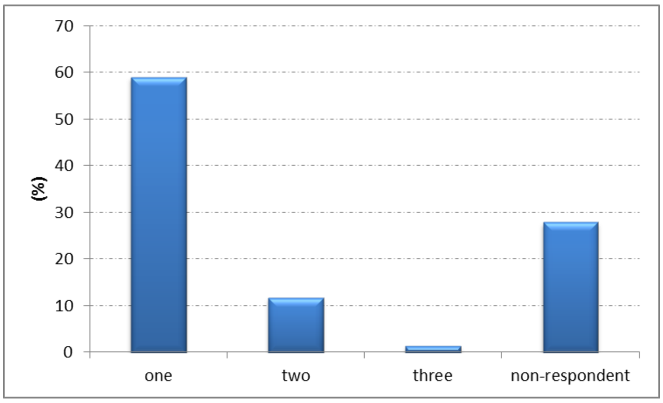


Figure 18: proportion of households with different number of freezers

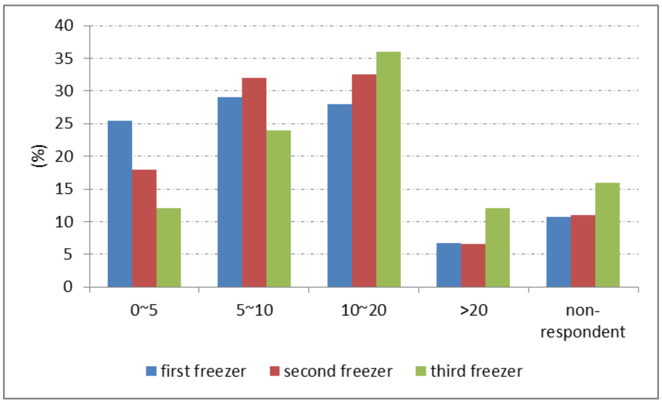


Figure 19: distribution of sample freezers in different age categories

3.3.3. Cooking appliances

The data collected with respect to ownership levels for cooking devices have been summarized in Figure 20. Since 92% of the households have electric ovens, dominant energy supply for cooking is electricity in the sample. A European study about household appliances shows the same penetration rate for electric ovens in Austria. Other kitchen devices that are almost available in most of the households are also presented in the Figure 20. No data on usage pattern and age of the kitchen devices have been found in the national statistical data or other studies in Austria, so in the survey people were asked to indicate the average time for using cooking devices and the age of their cooking appliances in their households.

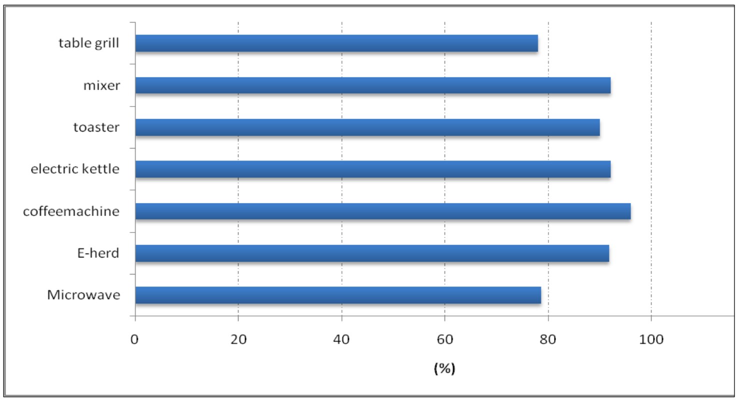


Figure 20: penetration rate of kitchen devices in sample

The result based on this study reveals that electric ovens are used in 22% of households between 15 to 30 minutes per use. 28% and 14 % of the households use electric oven between 45 to 60 minutes and more than 60 minutes per each use respectively (see Figure 21). 29% of the households have new electric oven, which has been bought in last 5 years but other 71% use their old devices.

In addition, Figure 22 shows that 75% of the households use electric oven every day.

Microwaves were owned by 79% of the respondents (see Figure 20). They are mostly used for warming up food, which is taking less than 5 minutes per use (71% of the respondents owing such an appliances).

Distribution of age of microwaves is like electric ovens. 30% of them have been bought newly from the market and the rest is older than 5 years. Daily use of microwaves happens in 60% of the households and 25% use microwave 2 or 3 times a week.

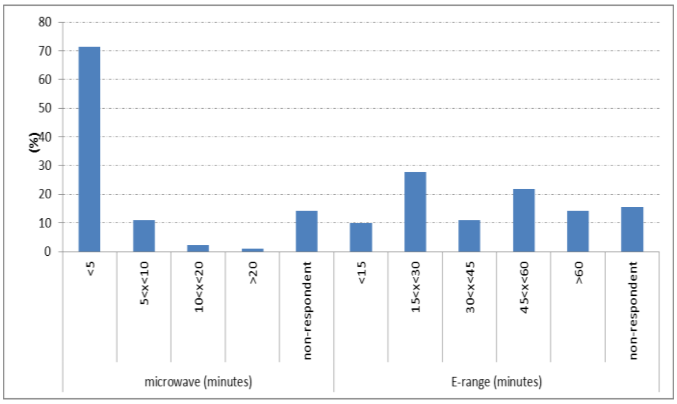


Figure 21: time of use for microwave and E-range

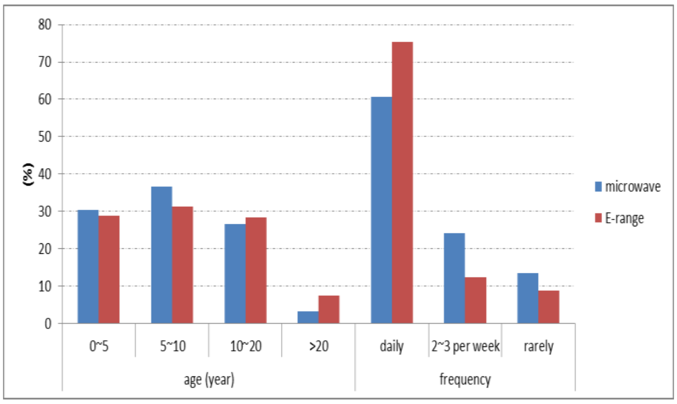


Figure 22: age and frequency of use for microwave and E-range

Figure 23 & Figure 24 show that retired persons have more time for cooking. Also increasing the number of the family members increase slightly the time of cooking with electro oven. It is also indicated that retired people use microwave more than other family categories.

Using frequency of other kitchen devices is depicted in Figure 25. Coffee machine is one of the popular kitchen devices, which has daily use in more than 75% of the households. Electric kettle staying in the second place 32% of households use it daily and 44% use it often.

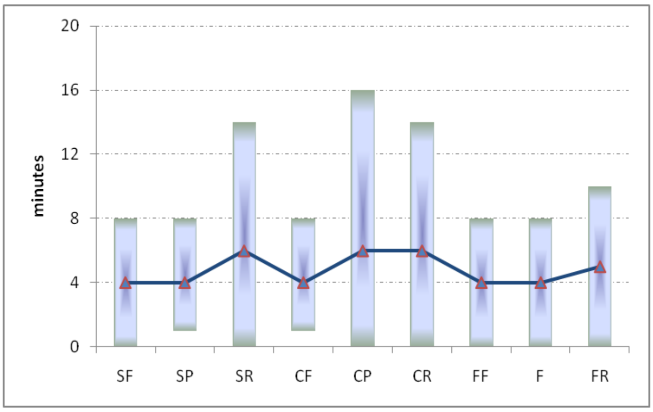


Figure 23: range of time using microwave

Figure 24: range of time using electric range

Although toaster and mixer exist in more than 90% of the households, they are rather in use sometimes or even rarely.

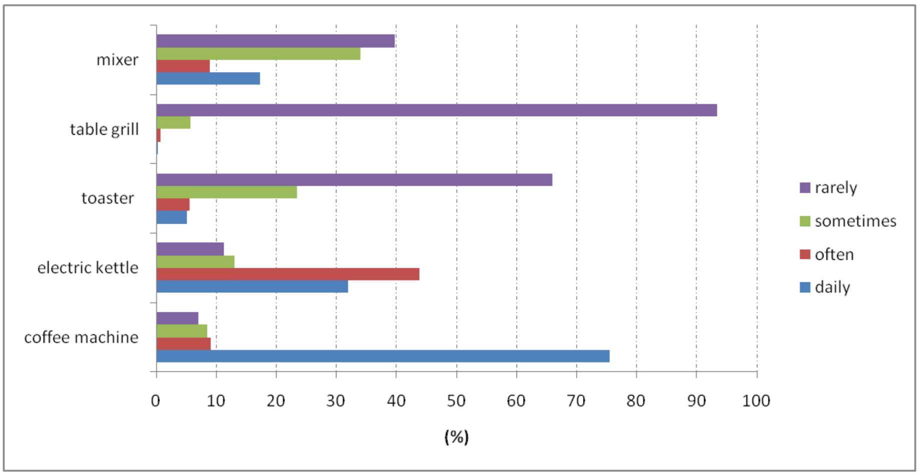


Figure 25: frequency of use of kitchen devices

3.3.4. Wet devices

Penetration rate of washing devices such as washing machines, tumble driers and dishwashers are 95%, 38% and 81% respectively (see Figure 26). Data from ADRES sample is comparable with data, which has been found in other Austrian literatures [56].

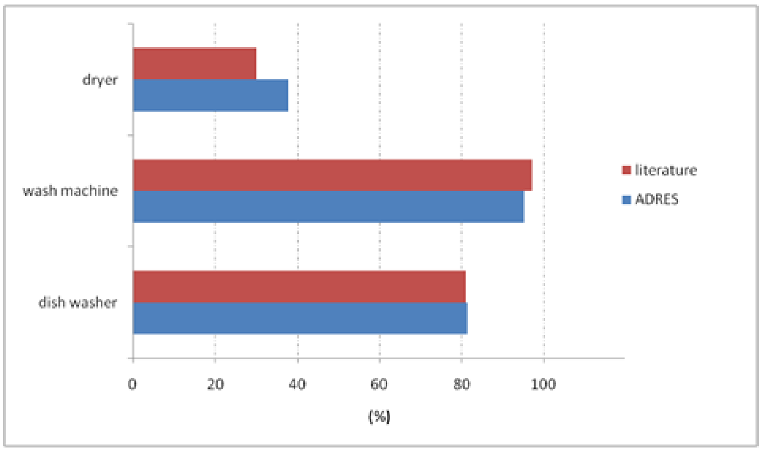


Figure 26: penetration level of white goods

Wash devices usage pattern were obtained by asking the respondents to indicate the number of cycles usually employed per week.

It is obvious that washing devices have different programs, which would be distinguished by water temperature during the wash cycle. Type of wash program has not been asked in the questionnaire but the average number of wash cycles was considered further.

The total number of wash cycles for wash machine and tumble dryer per household ranged from 1 to 11cycles per week (Figure 27 & Figure 28). The number of the wash cycles for washing machine is almost the same in summer and winter. Tumble dryers have converse situation. It is more in use in winter because of lack of sunny days and low outside temperature.

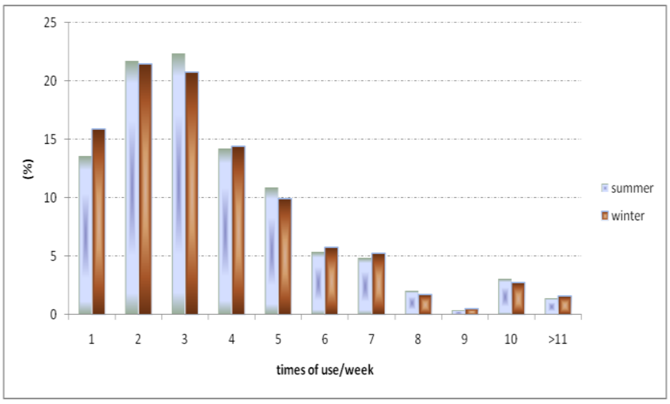


Figure 27: proportion of households according to number of wash cycles per week for washing machine

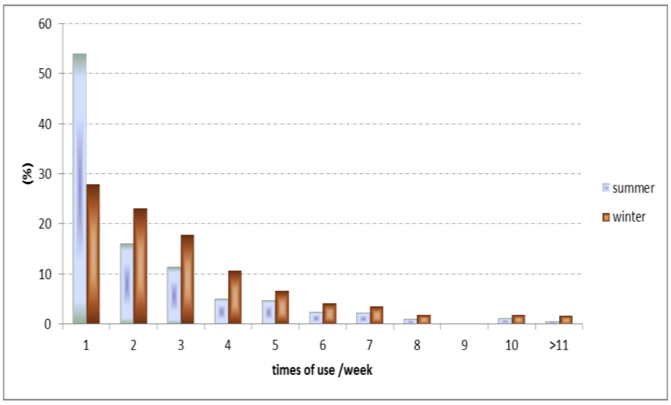


Figure 28: proportion of households according to number of wash cycles per week for tumble dryer

According to Figure 29 & Figure 30 wash cycles in wash machine and dryer are highly dependent to the family type and mostly on the number of the people per household.

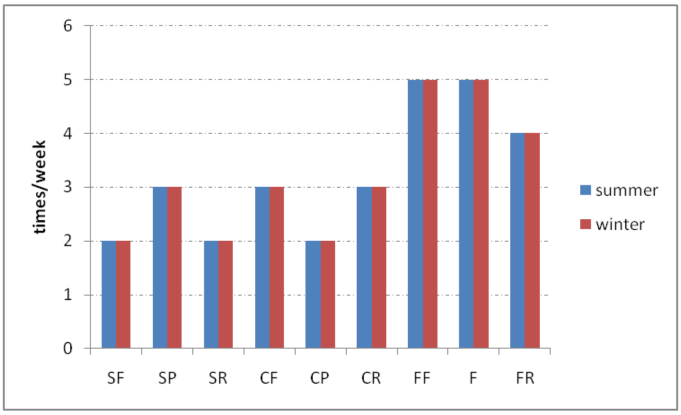


Figure 29: number of wash cycles for washing machine regarding defined family types

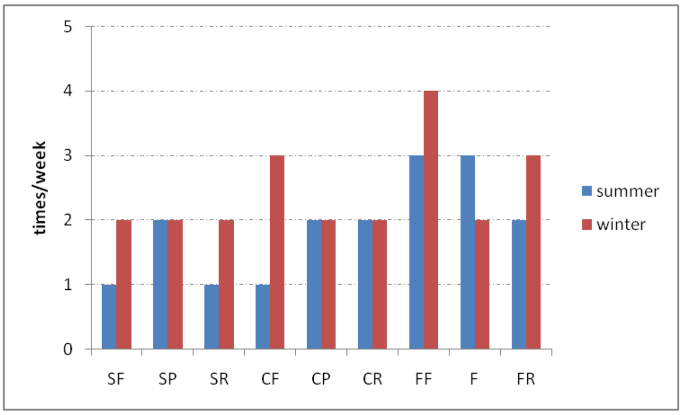


Figure 30: number of wash cycles for tumble dryer regarding defined family types

Usage pattern of dishwasher has been asked generally independent to the season. Number of wash cycles also ranged from 1 to 11 per week (see Figure 31). Figure 32 shows that like other wet devices, household size and type of the family are influencing the number of the wash cycles per week.

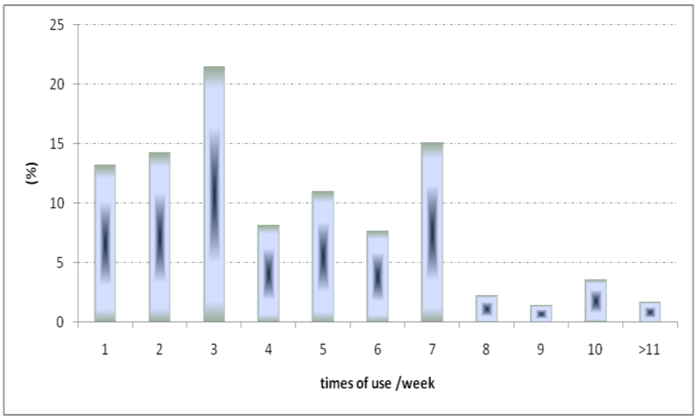


Figure 31: histogram of number of wash cycle per week for dishwasher

Figure 32: number of wash cycle per week according to family type

In questionnaire, it was also asked about the age and energy labeling of white goods. In Figure 33, the inner ring is related to wash machines. As it is seen 15% of the households have wash machine with A+ energy class, 71% with A and rest are in energy class B,C and D. The outer ring shows the same information for tumble dryers. The number of dryers with energy class A+ is more than that for wash machines. 26 % of tumble dryers and 14% of washing machines in the sample are inefficient and energy wasting.

The efficiency ring of dishwashers, which is also related to the age, shows that 37% of dishwashers were almost new purchased and other 63% are older than to be categorized in "A" energy class (see Figure 34).

Since the last 10 years energy labeling of white goods has made a significant progress and is going to take another step in 2011. By releasing of each new energy standard for household devices, the energy consumption of labeled devices will be decreased.

Energy class A+ emerged in 2003 and made a revolution in the energy demand of household's white goods. If the year 2003 is defined as an index year, the results of investigation show, that 60% to 70% of the households white goods are beyond efficient available devices in the market.

On the other hand, each device has its expected useful lifetime. Average useful life of Cooling and wet devices is 15 years. If it is considered that devices should be replaced when their useful lifetime expired, there are almost 30% potential of saving energy via replacement of dead devices with efficient available one in the market.

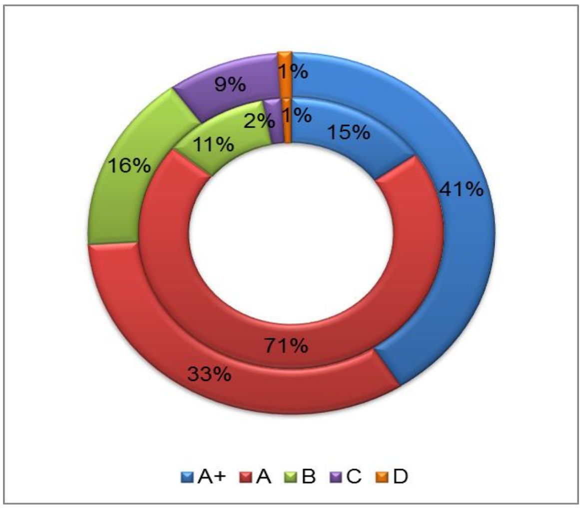


Figure 33: Distributed energy classes for washing machines (inner-ring) and dryers (outer-ring)

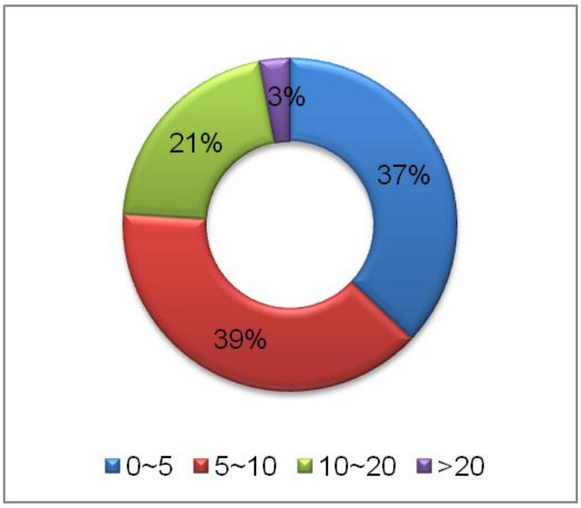


Figure 34: Distributed age classes for dish washers

3.3.5. Brown goods

There is diversity of brawn goods in the households. Table 3 depicts the average number of brawn goods categorized as entertainment-, office- and miscellaneous devices.

TV, sat-receiver and PC including laptops are multiple devices with average number of 1.9, 1.05 and 1.14 per household respectively.

Table 3: penetration rate of brown goods

entertainment	Music center	sat-receiever	video recorder	dvd player	hard disk	TV
No. / HH	0.94	1.05	0.66	0.73	0.15	1.9
office	laptop	pc	LCD Monitor	CRT Monitor	printer	scanner
No. / HH	0.54	0.67	0.47	0.21	0.73	0.32
miscellaneous	toothbrush	fax	answering	coreless-phone	play station	projector
No. / HH	0.58	0.13	0.17	0.52	0.20	0.01

LCD monitors are more popular than old CRT ones but according to Figure 35, CRT TV's are still in use in more than 60 percent of households. For entertainment and office devices there are no European energy labeling. For some office devices like Monitor "Energy STAR" program [57], a program developed by the US Environmental Protection Agency (EPA) to make energy-saving office equipment, is applicable. According to Energy STAR standard program, resolution and pixel of the Monitor defines the power consumption of the monitor in different defined mode of use like active, off, sleep mode.

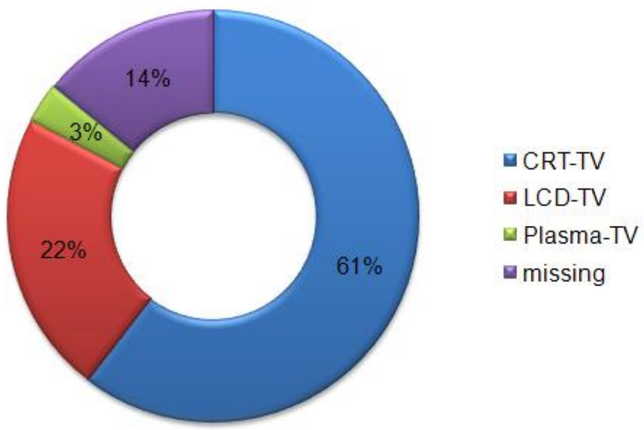


Figure 35: distribution of various types of TV

3.4. Consumption development and energy labeling

Reducing energy consumption and eliminating wasted energies are main goals of the European Union (EU) since 2003. For meeting the commitments on climate change made under the Kyoto Protocol, EU pledged to cut its annual consumption of primary energy by 20%, increase the share of renewable resources by 20% and decrease the amount of greenhouse gas emissions by 20% till 2020.

Since the energy demand in domestic sector accounts for 25% of the final energy needs in the EU, the energy efficiency of household appliances play an important role on achieving the goals of 20-20-20 target.

Electricity use of household appliances is increasing considerably since 1970. Higher standards of living and comfort, multiple purchases of electric appliances and the growing need for air-conditioning are main reasons for this trend to prevail. Energy consumption by consumer electronics and new media as Internet is also steadily growing (see Figure 36). Higher percentage of share of renewable energies in producing electricity since 2005 is a big step to reach 20-20-20 target (see Figure 37). It leads to increase the share of renewable resources in producing electricity and at the same time decreasing the CO2 emission.

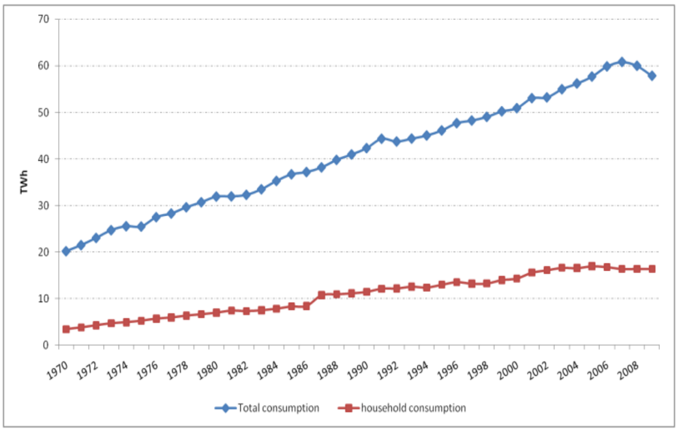


Figure 36: annual electricity consumption of domestic sector in Austria

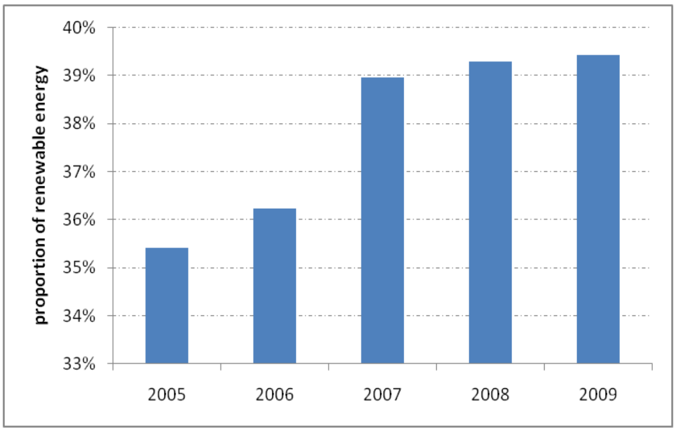


Figure 37: share of renewable resources in producing electricity in Austria

For getting the response to continuously increasing demand in the domestic sector two complementary ways can be implemented.

1. Energy labeling of household appliances: increasing the consumers awareness on real energy use of household appliances like cooling-, wet-, cooking- and entertainment devices through clear labeling.
2. Minimum Efficiency Requirements: in addition, compulsory minimum efficiency requirements will encourage producers of household appliances to improve the product design and energy consumption.

The purpose of introducing labels is to convince consumers to buy and manufacturers to produce appliances that are more efficient.

Household appliances standards have more than three decades history but it became popular just after oil price shock in 1970 [58].

EU decided to put rules on efficiency and energy labeling of household appliances since 1992. Provisions on energy labeling of cooling devices like refrigerators and freezers were established by directive 94/2/EC [59].

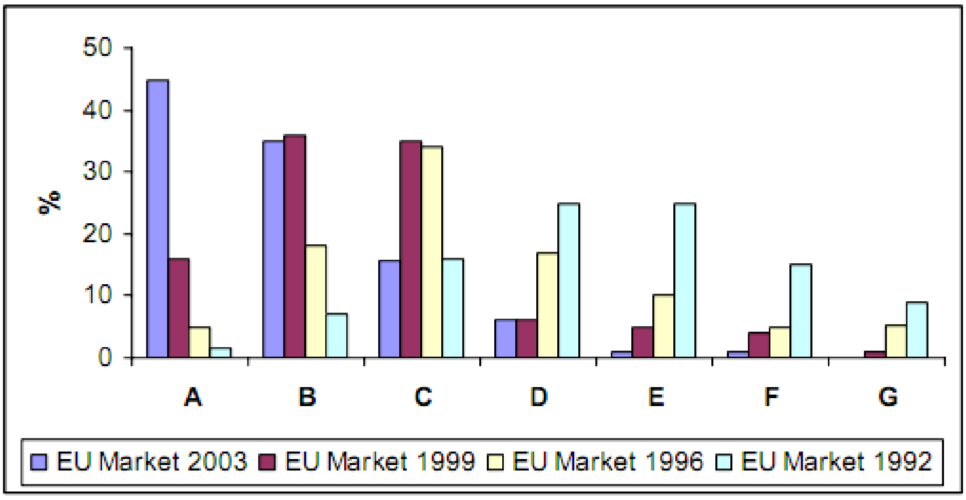


Figure 38: distribution of refrigerators energy classes in the market since 1992

Figure 38 shows the share of refrigerators with different efficiency classes in the EU market. Energy class A entered the market after directive 94/2/EC. About 20% of the cold appliances sold in 2000 were in the most efficient class A and in some markets; the proportion was more than

50%. Higher share of A class appliances in the market caused the new labels A+ and A++ to be designated in directive 2003/66/EC [60].

Recently, according to Directive 2010/30/EU another additional energy class A+++[4] will be added to device's classification. Energy class A+++ must be applied from 31 July 2011 [61].

Figure 39 and Figure 40 show the development of energy consumption via energy labeling for refrigerators and freezers. It is clear that there is a big difference in the annual energy consumption of high efficient devices having A++/A+/A compared to inefficient one categorized B/C/D energy classes. Energy class A+++ is supposed to enhance the energy consumption and guarantee energy savings up to 50 % over conventional class A in white goods.

Using most efficient appliance in the household not only helps saving energy and consequently money but also speed down global warming and climate change.

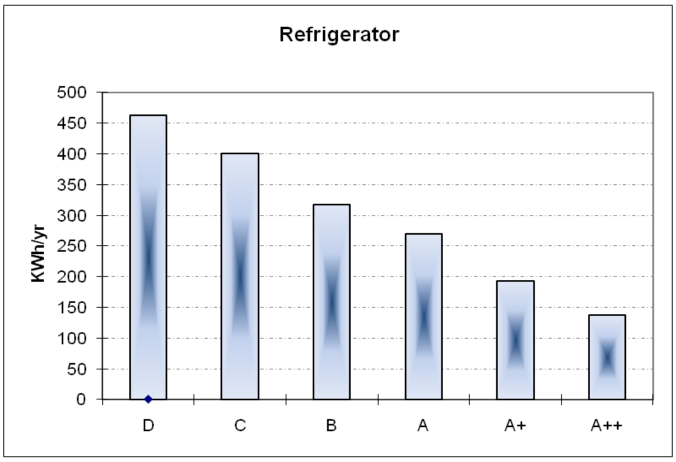


Figure 39: development of refrigerator's annual energy consumption via energy labeling

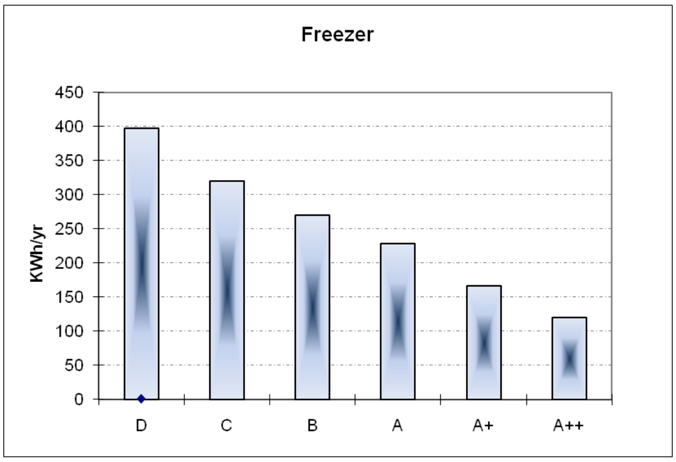


Figure 40: development of freezer's annual energy consumption via energy labeling

[4] Each plus (+) in front of energy labeling class A is supposed to be 20% lower annual energy consumption compare to A energy class

Wet device like washing machines and dishwashers also started to have energy labeling via directive 95/17/EC [62] and 97/17/EC [63] respectively. In 2008, washing machines with energy-class A/A+ and dishwasher with energy-class A were dominant in the market and proportion of sales.

Figure 41 and Figure 42 presented annual energy consumption of washing machine and dishwasher according to the number of their use per week. It is seen that energy labeling has a major affection on the annual energy consumption of mentioned appliances.

As it is mentioned before, since September 2010, new scale ranging of energy labels from A+++ to D for dishwashers, washing machines, fridges and freezers introduced to the market.

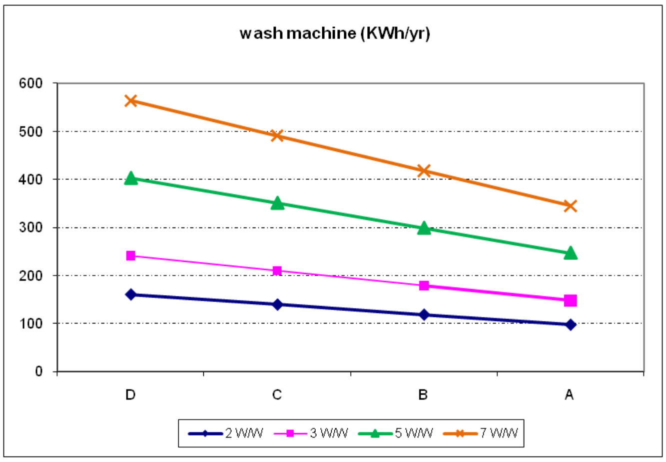


Figure 41: annual energy consumption of washing machine via development of energy classes

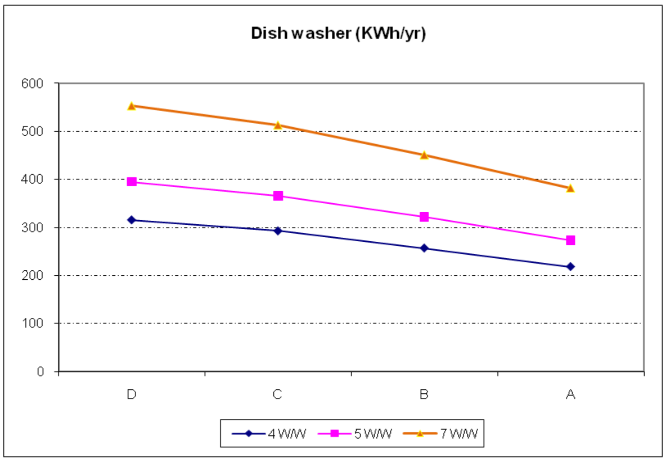


Figure 42: annual energy consumption of dishwasher via development of energy classes

Devices in the energy efficiency class B to G must vanish from the shops in 2014. Instead, there are future classes A, A+, A++ and A+++. The differences between these, however, are huge: Roughly, as expected each Plus on the label for a 20 percent higher efficiency and therefore lower energy consumption. An "A+++"- fridge would be therefore 60 percent more efficient than a device with energy efficiency class "A". The difference makes itself felt but in a smaller electricity bill. However, means any additional benefits and higher cost.

Regarding new directive on 2010/30/EU, televisions will also be set up with energy labeling until 2014. The electricity used by televisions accounts for a significant share of total household electricity demand in the EU countries and televisions with equivalent functionality have a wide disparity in terms of energy efficiency. Therefore, energy labeling should cover televisions to make a significant improvement in their energy consumption in near future.

Result of ADRES survey shows that the average number of refrigerators and freezers per household are 1.2 and 0.9 respectively. According to 3.6 million households in Austria in 2008, there are 4.3 and 3.1 million stocks of refrigerator and freezer in Austrian Households respectively.

Regarding to gathered data, 25% of the refrigerators have been bought in the last 5 years, 29% in the last 5 to 10 years, 27% during last 10 to 20 years and 19% are older than 20 years. Data from GfK[5] depicts the distribution of different energy labeling of cooling devices since 1994 to 2008 in the household market (see Figure 43).

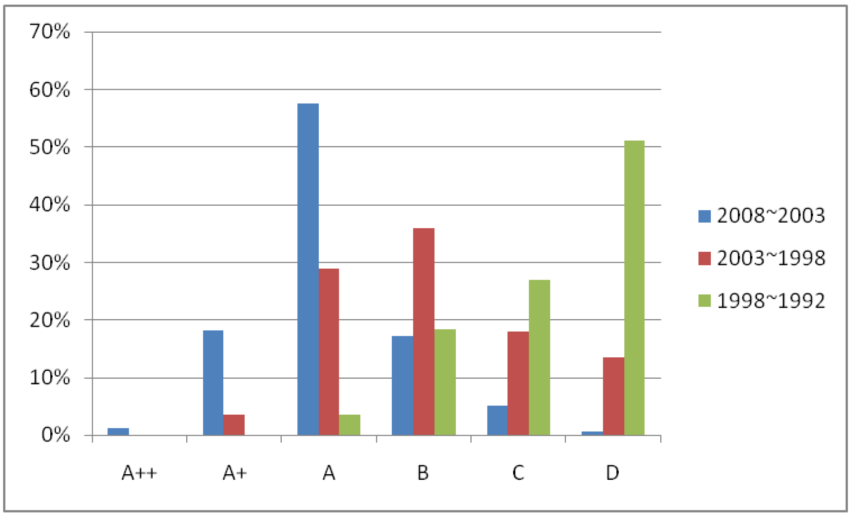


Figure 43: distribution of cooling devices according to their energy classes

5 Gesellschaft für Konsumforschung

Combining these two data from ADRES survey and GfK, make it possible to calculate the number of cooling devices in different energy labeling classes for sample and extend it to Austria. In Figure 44, lines are presenting the number of refrigerators and freezers in million in Austrian households. Columns are presenting the total energy consumption of these cooling devices in Austria. Depicted curves in Figure 44, reveals that although the number of freezers are almost same in energy class B and C but the energy consumption in class B is considerably less than class C. there are same observations for refrigerators in energy class A and B.

If all of existing devices are replaced with A+++ one, 1.7 TWh energy could be saved each year.

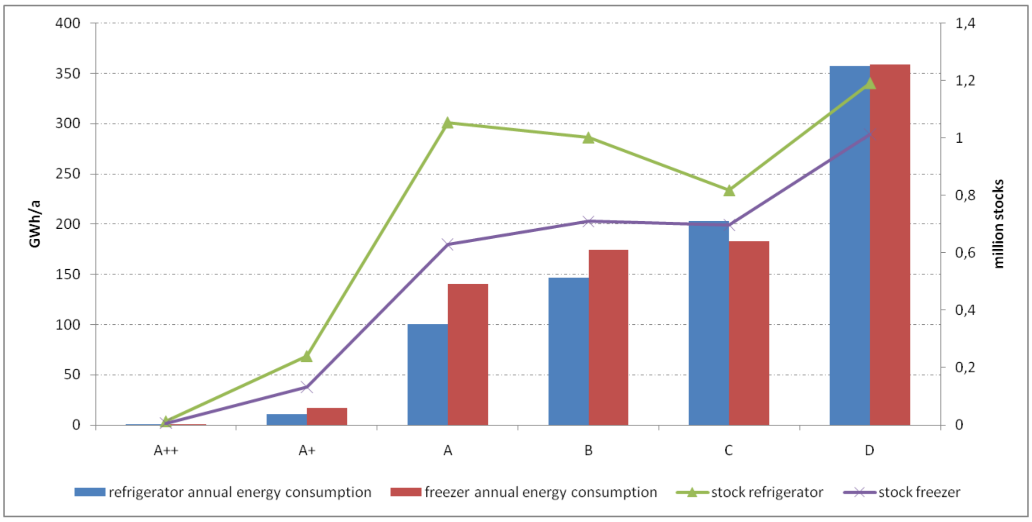


Figure 44: distribution of cooling devices and their annual energy consumption in Austria 2008

Directly from the ADRES sample data the energy class of wet devices has been extracted. As it is seen in Figure 45, energy class A is dominant in washing machines and tumble dryers and energy class B is major trend of market for dishwashers.

Up to year 2008, there were no higher energy classes in the market but new legislation in European commission brings A+, A++ and A+++

energy classes to the market in 2011, which have up to 30% lower energy consumption in comparison to A class.

Even among existing energy classes, there is a significant difference in the amount of annual energy consumption. For example according to Figure 45, the same number of dishwashers with various energy class A and B, do not have same amount of energy consumption over a year. In this case, enhancement of energy consumption via standard energy classes will save almost 17% of energy compare each year.

Replacing all the old wet devices with most efficient one in future will save 1.5 TWh per year.

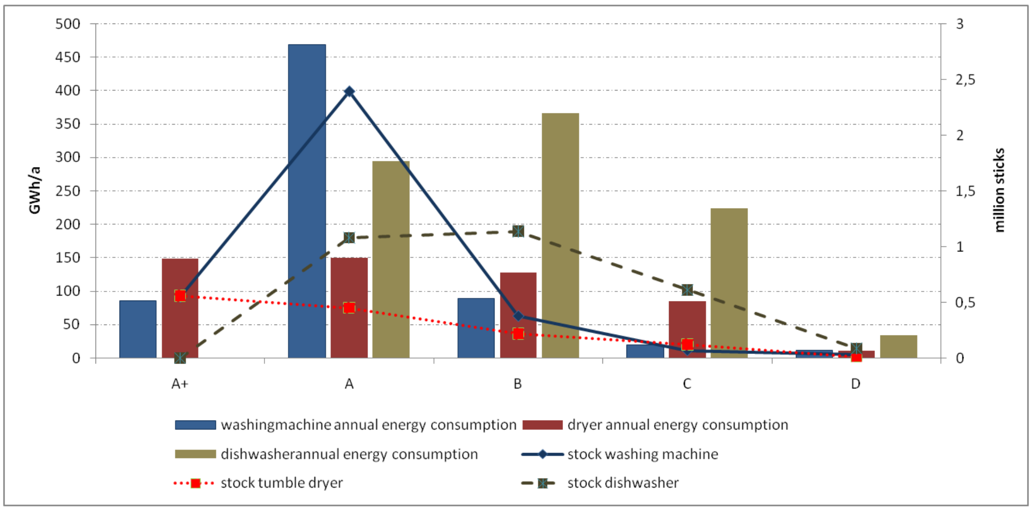


Figure 45: distribution of wet devices and their annual energy consumption in Austria 2008

According to ADRES sample, the average number of TV per household is 1.9, which is accounting as 6.8 million stocks in Austrian households.

TV is in use in households in average for 5 hours. Dominant available energy labels for TV are B energy class with average power consumption about 80 watts, which means roughly one TWh energy consumption per year in Austria. Replacing all TVs with current best available technology would save 0.25 TWh energy per year. Even by upcoming new labeling program for TV sets energy saving amount would reach 0.4 TWh per year. The mentioned saving potentials has been calculated in the case of keeping the user behavior as it is and just considering old inefficient devices would have been replaced with new efficient one in 2008.Nevertheless, result of study shows that changing the user behavior can also help to decline energy consumption. As an example, reducing the number of multiple devices like refrigerator and TV or reducing the number of wash cycles in washing machine and dishwasher with reducing the number of half load washes to full load washes can be mentioned.

3.5. Energy saving potential

3.5.1. Vision: Austria 2020

Using all statistical data extracted from ADRES survey, discussed in above sections, make the possibility to estimate the energy consumption of white goods including TV in whole Austria (see Figure 46).

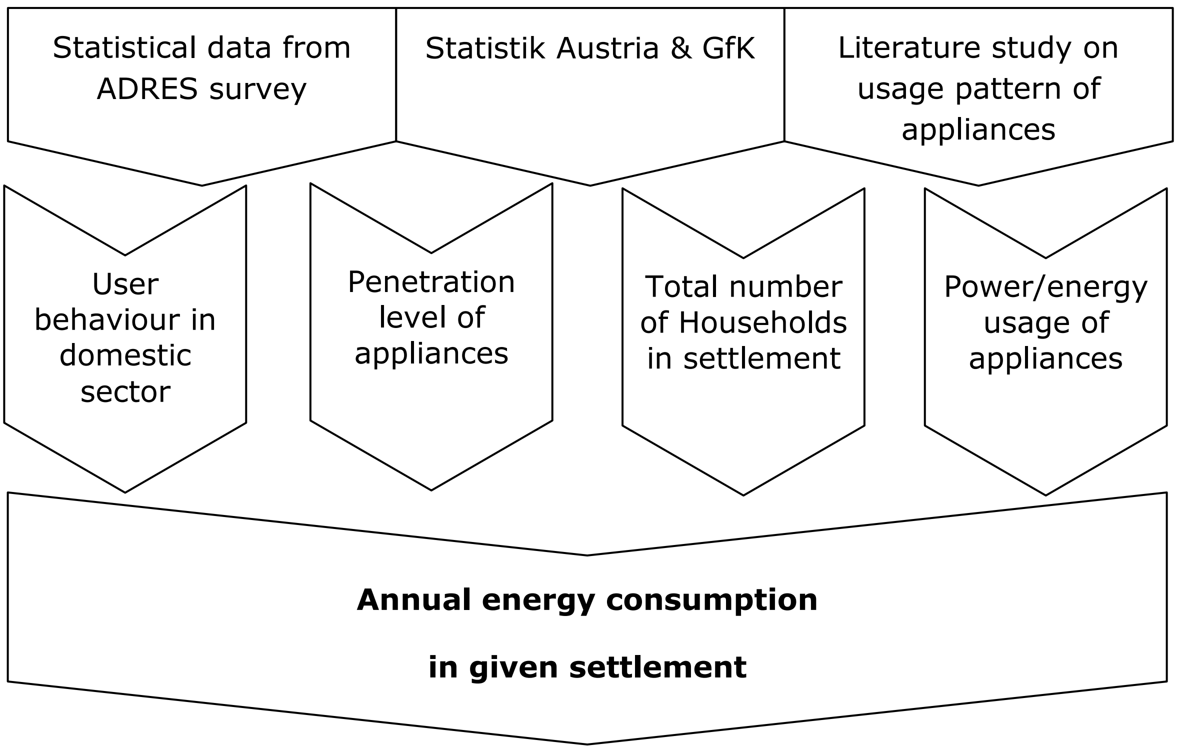


Figure 46: Schematic depiction of calculation method for energy vision 2020

Table 4 shows the assumptions that have been taken according to the ADRES survey and other literature studies.

Table 4: assumptions in calculation of energy vision 2020

	Washing machine	Tumble dryer		Dishwasher		TV
Capacity (kg)	5/6	5/6	Capacity (Lit. of water)	11	size	Average
Cycle/week winter	4	3	Cycle/week winter	4	hour/day winter	6
Cycle/week summer	4	0	Cycle/week summer	4	hour/day summer	5

Values in Table 4 are considered for an average household in Austria and family types are not taken into account.

Table 5, gives an overview of energy consumption of white goods including TV in 2008 and 2020.

Table 5: Overview of energy consumption of white goods including TV

Appliances	penetration factor	Stock in million 2008	Energy 2008 (GWh/a)	penetration factor	Stock in million 2020	Energy 2020 (GWh/a)
Refrigerator	1.20	4.28	982	1	3.88	355
Freezer	0.90	3.21	869	1	3.88	419
Washing machine	0.95	3.39	901	1	3.88	706
Tumble dryer	0.38	1.36	186	0.5	1.94	159
Dishwasher	0.81	2.89	897	1	3.88	590
TV	1.90	6.78	1443	1.2	4.66	477
Sum			5279			2707
Number of HH	2008 3,57 million			2020 3,88 million		

In the course of census, data received from statistic Austria show that there are 3.57 million households in 2008 in Austria. Using the current penetration level of white goods derived from ADRES survey and energy consumption of devices regarding their energy classes, leads to calculate the number and energy consumption of white goods that are in used in Austrian households.

Number of stocks of household in Austria in 2020 has been prognosticated by Statistic Austria. Considering the trend of penetration level of household devices in future and taking into the account, that A+++ will be dominant energy label in the market, make it possible to calculate the energy consumption of white goods for 2020 as well.

Comparing the estimated energy demand of white goods including TV for 2008 and 2020 shows that, by replacing the current devices with most efficient one and changing the user behavior in the terms of reducing the multiple devices and decreasing the half load wash cycles to full-load cycles in wet devices, almost half of energy demand can be saved.

Among whole saving potentials, 60% is related to cooling devices, 30% to wet devices and 15% to TV.

Extending the European energy efficiency directive to brown goods and even other electrical devices not only in the household sector but in other consuming sectors would have considerable effect on the total energy consumption.

3.5.2. Vision: Austrian Household

In order to get a feeling of the effect of energy efficiency and efficient user behavior in the domestic sector, annual energy consumption of dwelling according to size of household has been estimated. Figure 47 depicts the input references and assumed data for further demand estimation. Energy usage of best available household appliances has been collected via literature studies and above all Information platform for high-quality, energy-efficient products.

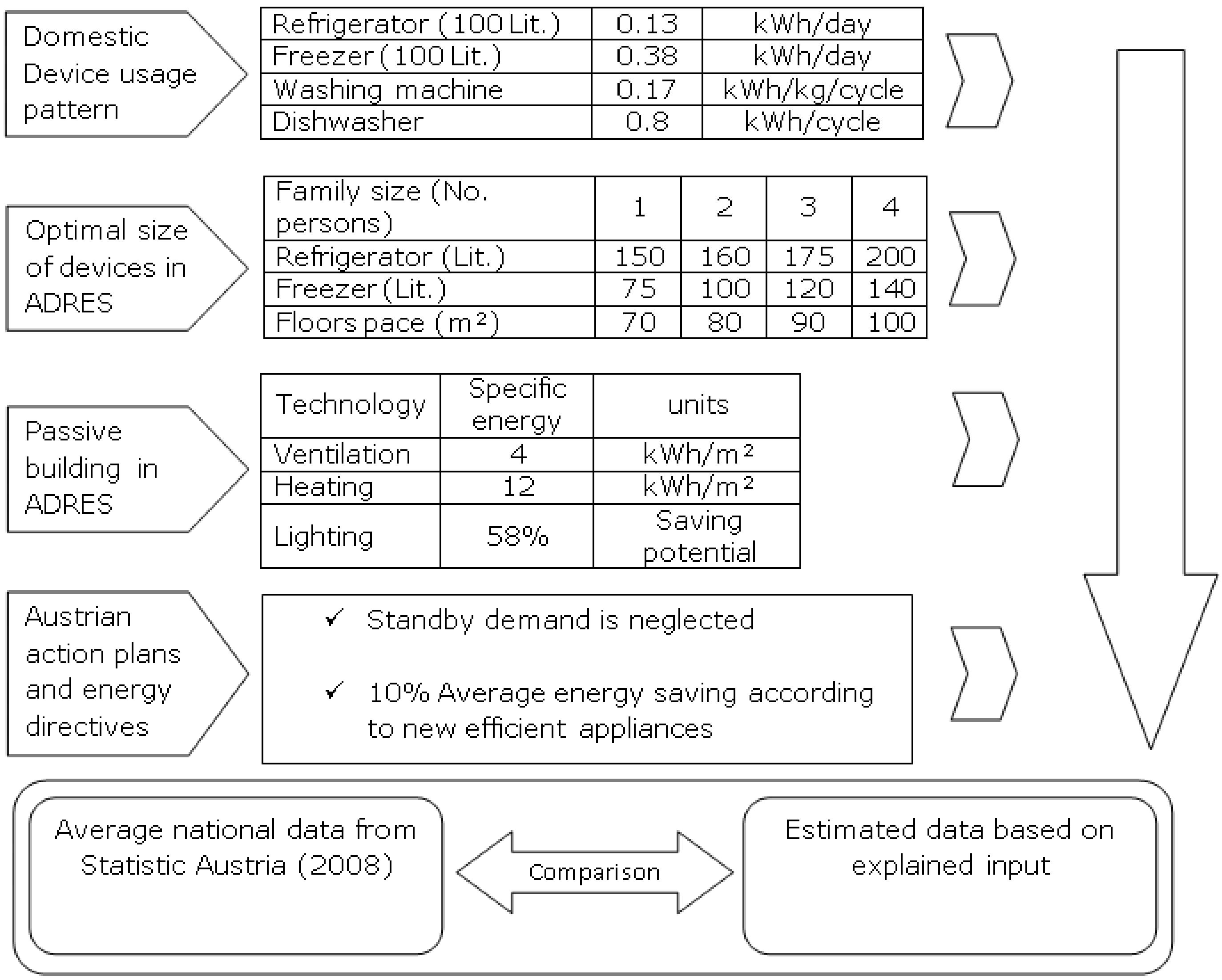


Figure 47: Schematic of calculation method for energy vision in Austrian households

User behavior and enhanced size of white goods required in different households has been extracted from ADRES survey. In addition, it is considered that a future building is a passive building. Energy demand of passive houses for lighting, heating and ventilation has been got from result of a research study ADRES.

On the other hand different energy directives and action plans running in Austria and other European countries are the references for removing standby energy consumption and slight reduction of other small electric devices. Estimated annual energy demand of households in different device categories is listed in Table 6.

Table 6: Annual energy consumption in ADRES & national house in Austria

	1 Person		2 Persons		3 Persons		4 Persons	
Values in kWh	Statistic Austria	ADRES	Statistic Austria	ADRES	Statistic Austria	ADRES	Statistic Austria	ADRES
Total demand	2831	1924	3580	2612	5756	3235	5818	3698
Refrigerator	255	82	334	88	362	96	329	110
Freezer	137	104	203	139	338	166	332	194
Electric range	176	116	337	289	444	387	524	524
Washingmachine	96	44	171	88	265	159	251	212
Tumble dryer	19	0	38	0	91	0	176	0
Dishwasher	57	83	166	125	238	166	324	208
Kitchen & household devices	82	82	172	172	197	197	226	226
Office devices	69	62	86	77	141	127	120	108
Entertainment devices	122	110	179	161	255	230	235	212
Communication devices	18	18	34	34	33	33	33	33
Chargers	8	8	19	19	24	24	26	26
Ventilation	188	280	117	320	168	360	168	400
Office Standby	11	0	9	0	15	0	19	0
Entertainment Standby	96	0	117	0	181	0	152	0
Range and oven Standby	7	0	15	0	25	0	19	0
Kitchen & household devicesStandby	19	0	32	0	36	0	44	0
Lighting	224	94	335	141	499	210	586	246
Water heater	590	0	579	0	928	0	1090	0
Electrical heating	655	840	638	960	1515	1080	1164	1200
Percentage of saving potential		32%		27%		44%		36%

Regarding Table 6, required energy for ventilation will be increased because of nature of passive houses and their need to have regular circulated air in the system. Heating and lighting energy need will be decreased by 70% and 58% to their counterpart standard house respectively. Wet and cooling devices have lower consumption just by replacing the current devices with best available technologies in the market.

All above mentioned efficiency measures leads to save 27% to 44% in the final annual energy consumption of households in Austria.

3.6. Conclusion & Summary

In addition to the promotion of micro generation in order to increase the share of renewable energies and achieve 20-20-20 EU-target, energy efficiency plays an important role in Austrian energy policy plan [64].

According to Austrian energy strategy, the final energy consumption in Austria in 2020 should be reduced to 1,100 PJ. Final energy consumption in Austria was 1,440 PJ and 1,353 PJ in 2008 and 2009 [65] respectively. This means that by almost 24% decline in total energy consumption or 3% consumption decrease per year until 2020, Austrian energy target is not far from reality.

The result of investigation in first part of the study reveals, that the domestic sector as second largest energy consuming sector has considerable energy saving potential. Through observance of energy-efficiency measures, not only total energy consumption will be reduced and national and international targets will be covered but also there are also additional benefits for the Austrian economy in the terms of reducing import capacity and increasing the security of energy supply system.

Using best available appliances optimize the size of needed devices, altering the user behavior in 0rder to use energy efficiently and building passive houses instead of current normal buildings are the measures, which will help to reach the mentioned goals.

Part II

Power autonomy

Chapter 4

Stochastic model for household's load profile

4.1. Introduction

Exploratory analysis of the energy consumption of households, which was described in the first part, provided an overview of energy consumption of household devices in the domestic sector. For designing an autarchy settlement in a renewable dominated micro grid, not only it is important to consider the annual energy consumption, which should be covered up with supply side, but also generation units should be sized to fulfill the power demand in each instant.

In this regard predicting households daily energy consumption profile for early stage settlement planning is crucial.

There is a standard model for the household load profile, which is usually taken in use. This simplified model generates domestic load profile in 15 min. resolution depending on the season (i.e. summer, winter, transition period) and day types (i.e. working days, Saturdays, Sundays). The load profile is normalized to a yearly consumption of 1000 kWh. In order to simulate the load profile of any given household and family type, standard load profile should be scaled to the annual energy consumption of household.

Briefly regarding to the following given reasons, standard load profiles could not be used in this study.

- The generated load profile is an aggregated profile and individual usage pattern of household devices can not been extracted.
- The pattern of consumption is defined constant for any given family type
- The 15 minutes time resolution of synthetic load profile is not sufficient for the aim of this study

For simulating the households daily load profile, cross sectional analysis of data that have been got back from conducted survey is not enough. In addition, a time series analysis should have done to get the detail information about operation time of household appliances and make up for deficiency of standard load profiles.

Further sections will describe the drawbacks of standard load profile precisely and time series analysis of measured data will be explained.

4.2. Measurement campaign

Questionnaire respondents were asked to share weather they are interested to participate in measurement campaign. Among the interested customers, 40 households were selected to get the second needed data set.

Since upper-Austrian utility helped with preparing the time series data, the measurement campaign has been concentrated in the upper Austria (see Figure 48). Flag's size in the picture shows the density of distribution of measured households in the area.

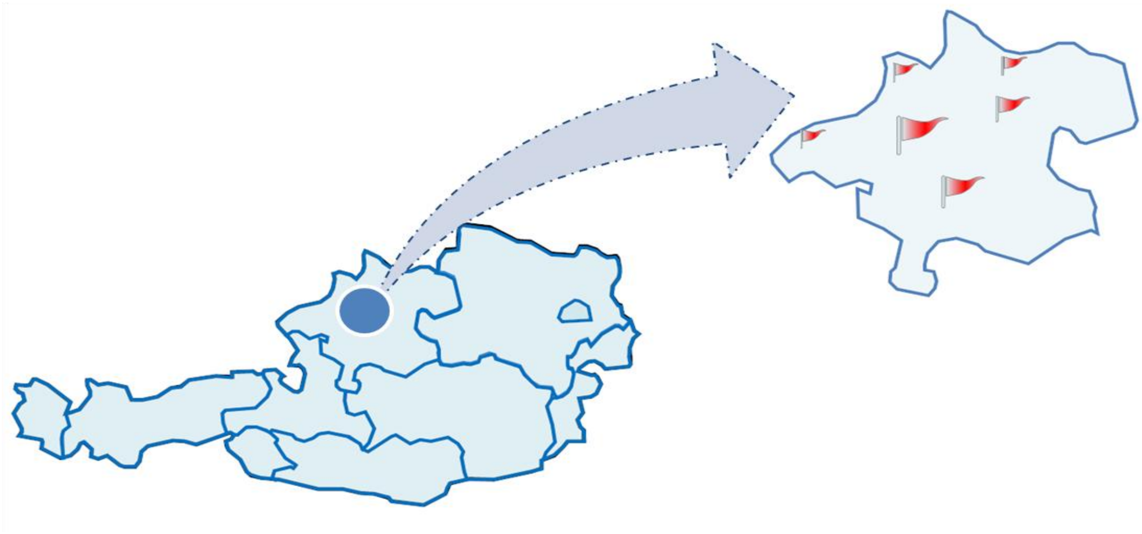


Figure 48: measurement champagne in Austria

Measurement campaign involved 40 selected households including 113 persons in 21 detached, 8 semi-detached houses and 10 apartments.

Data were collected in the time between 2009 and 2010 and encompasses 2 weeks in summer as well as winter including the installation and disassembly time of measurement tools. The total daily energy consumption and the energy consumption of possible individual household appliances was measured in each household. One-second time resolution was selected for measurements.

4.2.1. Measurement system & Database preparation

Two types of measurements are made in the measurement campaign. TOPAS[6] power quality measurement equipment was used for measuring the total energy consumption of each household in one second time resolution.

Measuring sensors of x-comfort home automation package from Moeller Company were used for measuring the individual devices in the household.

[6] Power quality analyzer

Since measuring the all-40 households was desired to be done simultaneously, enormous numbers of measurement devices were needed. In this regard, different smart plugs were examined, but concerning the high price of high quality and high error rate of low quality measuring devices, the idea of concurrent measurement had been failed. For covering the projects technical needs, measuring sensors of x-comfort home Automation package from Moeller Company were chosen. The plug measurement sensors are used to record the electrical consumption characteristic by current, voltage, active power and electrical energy for further data analyzing. Each individual device was plugged into a plug sensor and then into the socket. RF communication interfaces were used to integrate information from all sensors and data-loggers. If one of the electrical parameters (e.g. current, voltage, etc.) changes, changed value is sent to the logger and recorded in a text file.

Because of lack of TOPAS and x-comfort sensors, measurement has been done for each five household in the same time. After gathering all these text files from each household, the data have been extracted and saved in an excel data base in the sustainable way to comforting the data analyzing.

4.3. Analysis of collected data

Once the unique database was prepared, it was later on used for different data analyses. Since measured data have one-second time interval resolution, the size of database is enormous. It is necessary to make a pre-investigation to find the optimal resolution for predicting the load profile. It is clear that higher resolution affects the size of database and consequently the time of simulation.

4.3.1. Resolution of measurement

Most published information on electrical loads in Austria is in 15 minutes time resolution, which is the standard time interval for Austrian utilities.

15 minutes resolution is enough to show the variation of aggregated energy consumption across the customers for the aim of grid energy regulation and billing system, but it does not contain the information of high frequency variations in load [66]. In the domestic sector according to the diversity of the electric devices and various user behaviors, power consumption of devices can change significantly within few minutes, which will not be reflected in the averaged data over 15 minutes.

For example, Figure 49 shows one operation cycle of a washing machine in different time interval measurements. It is clear that measuring in various time intervals is equivalent to time averaging of higher resolution over longer period. In this example, the washing machine has been measured in one-second time intervals and the other resolutions are calculated arithmetically. Although the power pattern follows almost a similar pattern in all four curves, there are considerable differences when evaluating the power consumption, the peak power and the start and end time. Longer averaging time causes bigger failure and more inaccuracy in the load profile.

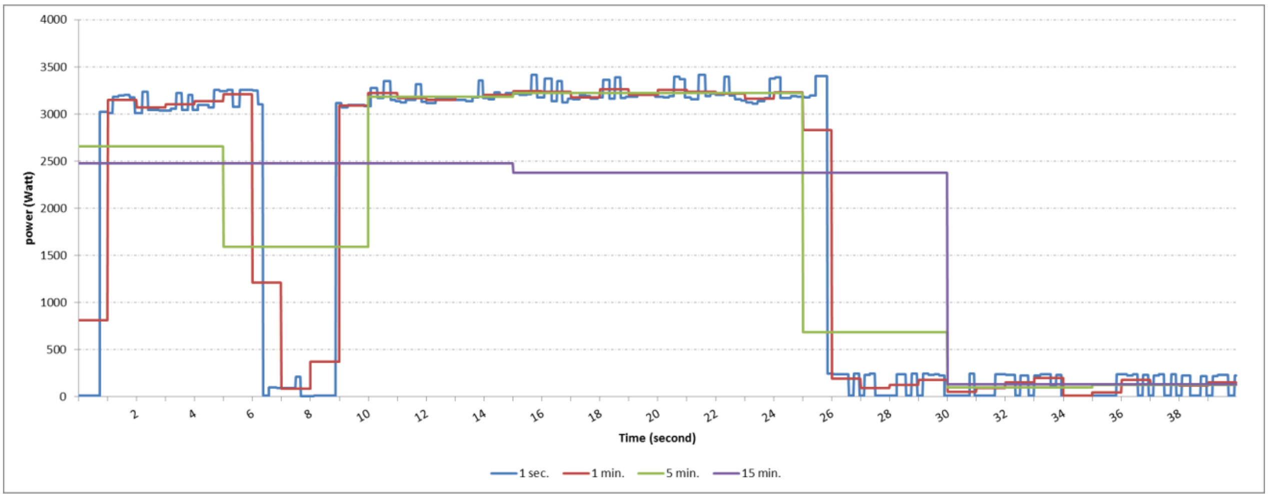


Figure 49: operation cycle of washing machine with different time intervals

As it is clear in the above figure, there is prewash program in the beginning that includes the heating up period with 3.2 kW power consumption. The process is following with few minutes drum spinning and again heating-up water for main washing cycle and in the end drum spinning for rinsing the cloths.

However, time averaging does not affect the surface area or rather the energy consumption over a given period but in an autonomous micro grid, it is also important to have an accurate estimation of load spike in order to be able to make power system balancing in time and to size the generation and storage units optimal.

For further analysis, the histogram of the dwellings demand over a day has been depicted in Figure 50 and Figure 51. The curves are shortened in the way to make the changes in power consumption visible. In order to make figures more clear only two houses with relatively high and low consumption are selected.

As can be seen in the diagram, both distributions are inclined to the left. Households with lower consumption have higher inclination, which shows the higher density of small devices in the household.

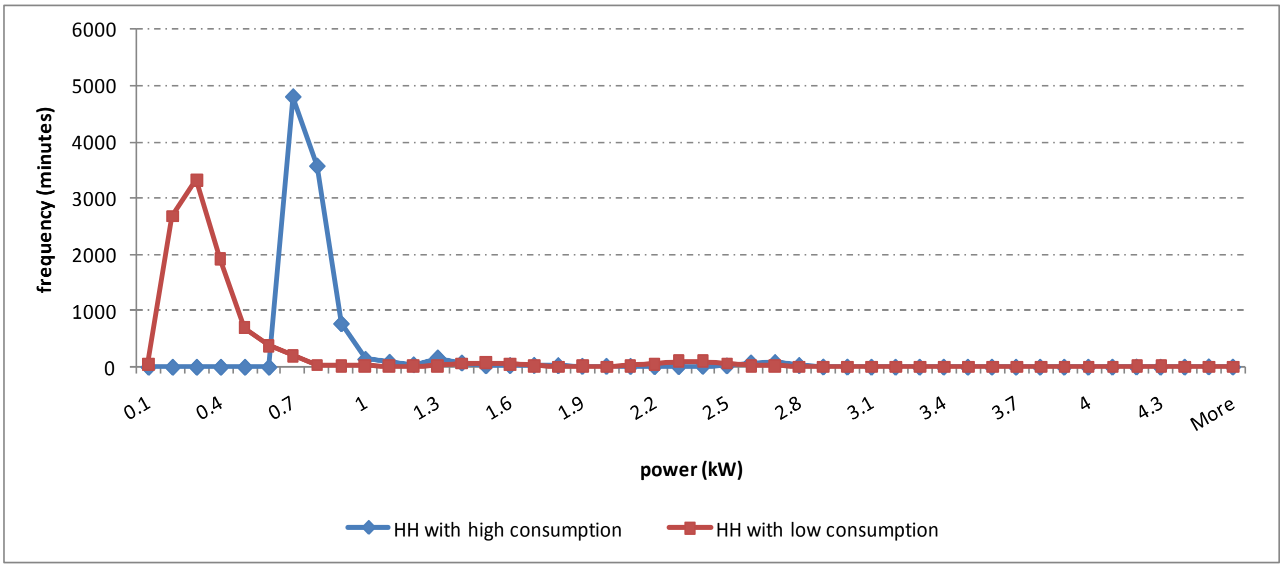


Figure 50: Histogram of the dwellings demand over a day

Since the frequency of higher loads is too small, another figure is used to show the considerable facts. According to Figure 51, loads between 2.8 and 4.2 kW are in use for almost one minute.

Using time averaging over a 15 minutes period would hide the load peaks, which is not desired in the design and feasibility study of autonomous micro grids.

In fact, for evaluation of power load profiles in this study are measured in one-second time interval. Considering the energy demand in 15 min. interval measurements by histogram analysis of frequency shows, that number of loads in use with a frequency of less than one minute are ignorable.

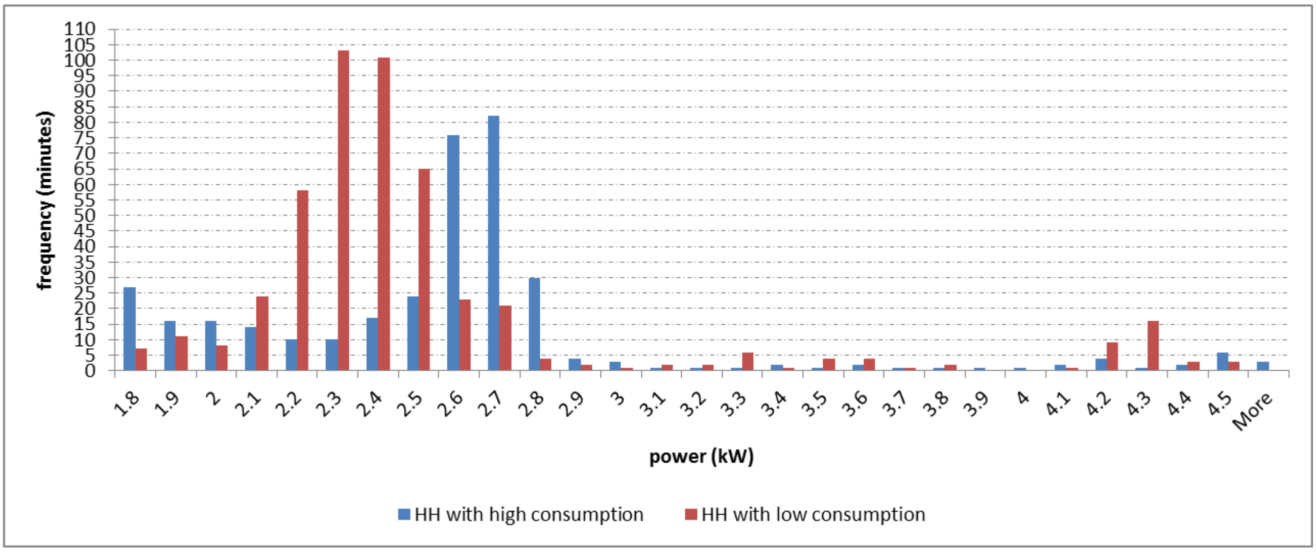


Figure 51: Histogram of the dwellings demand over a day

Figure 52, presents the total load profile of one household over a day with different time intervals. Original data measured in one-second intervals are used and 1, 5 and 15 min. intervals were calculated. Using time intervals over longer periods cause smooth load profile with higher based load and lower peak loads.

In an autonomous micro grid, for covering the mean demand of a household using the 15 min. load profile, a portion of renewable on site generation with 0.4 kW peak power seems to be enough for covering the daily consumption, while 1 sec. and 1 min. data show significant difference in the requested peak load.

The analysis of the effect of logging resolution on household load profiles shows that load profiles in an autonomous micro grid should be predicted in higher resolution. Although 1-second intervals has highest accuracy but logging in this resolution needs higher storage capacity and will speed down the simulation time. In this regard, one-minute resolution has been selected for the further part of the study.

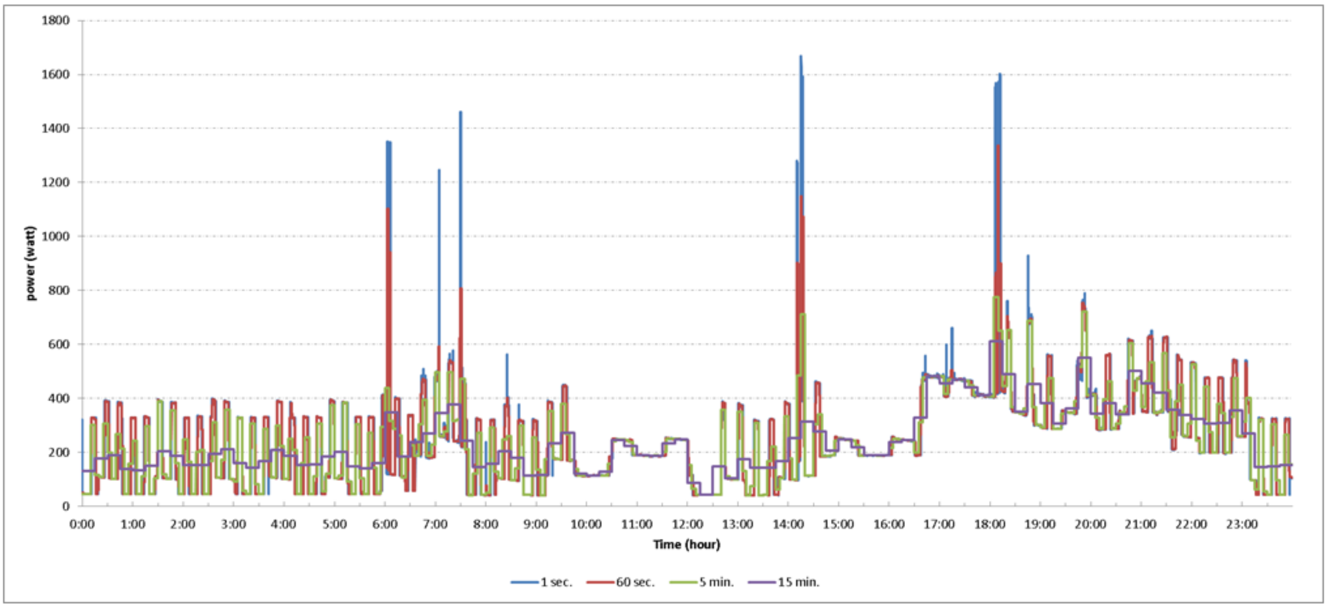


Figure 52: total daily load profile of a household with different time intervals

4.3.2. Analysis of Measurements

The database also can be used to indicate the effect of season, day type, family type and building type on the dwelling load profile. In the following, the precise results of data examinations are described.

Figure 53 to 56 show the structure of the load curves in hourly averaged time intervals. Household load profiles are split between weekends, workdays and two seasons. These curves were calculated by averaging the individual load curves for each household. The one-second values are merged per hour in order to obtain 24 values given in kilowatt-hour. This structure was obtained using all the monitored devices merged in appliances category (cooling appliances, office, multimedia, kitchen devices, heating, washing, Housework, etc.).

According to the diversity of electric devices in households, measured devices in defined categories are not similar in all observed households. Lighting is not included in the measurement.

It is clear that amount of peaks and base demand in winter is higher than in summer. Energy consumption in different device categories alters with changes in season and consequently in temperature. User behavior is inspired by the temperature deviation or rather seasons.

People spend more time in winter at home and therefore usage of office and kitchen appliances are higher than in summer. Heating category includes hot water and space heating. Since transition period has been merged into summer and winter days, there is also a space heating related amount of energy included in summer days load profiles.

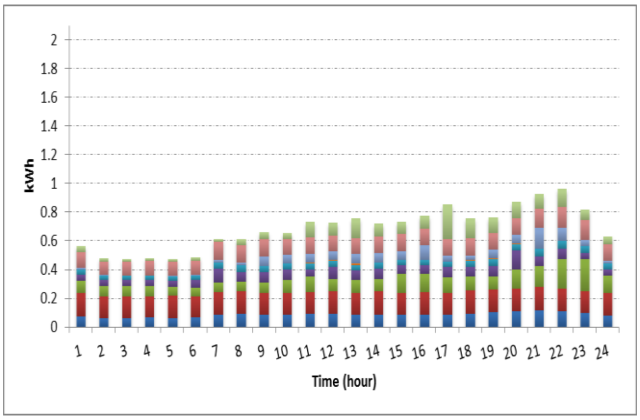


Figure 53: average usage pattern of households in a summer weekday

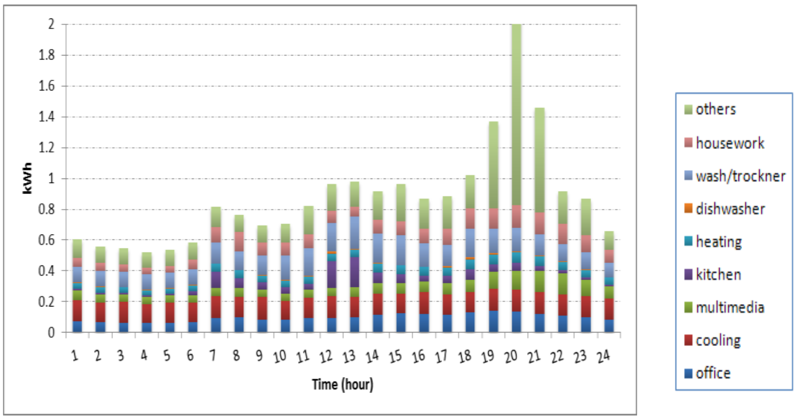


Figure 54: average usage pattern of households in a winter weekday

Not only the season but also the day type changes the pattern of energy consumption within a day. Weekend's morning load peak has disappeared from load profiles and the mid-day peak is higher than in working days.

Evening peaks occur sooner and generally, the rhythm of energy user behavior changes when the day type varies.

The investigation has been done just to make sure that whether the load pattern of measured households matches the common significant characteristic of standard load profiles. Day type and season should be considered as input parameters for further load profile prediction model.

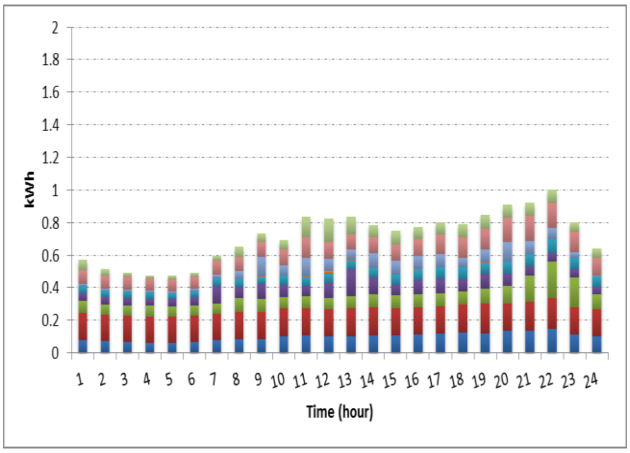


Figure 55: average usage pattern of households in a summer weekend

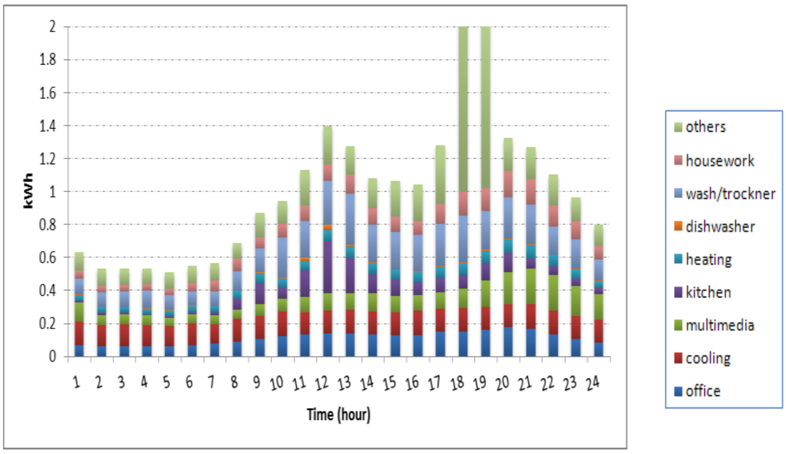


Figure 56: average usage pattern of households in a winter weekend

Figure 57 & Figure 58 show the effect of the type of building (detached / apartment) on the electricity load profile. Energy consumption in detached buildings is higher than in apartments. Space floor in detached buildings is normally bigger than in apartments and diversity of household appliances according to more space is higher than in apartments.

The type of building could be also an input parameter for household load profile prediction but the lack of data in observed households caused to ignore it in the further analysis.

4.3.3. Usage pattern or rather Occupancy profile

For building up load profiles, it is necessary to know the type and time of use of each device different households. The time of use and usage pattern of each device is related to the occupied period of the house.

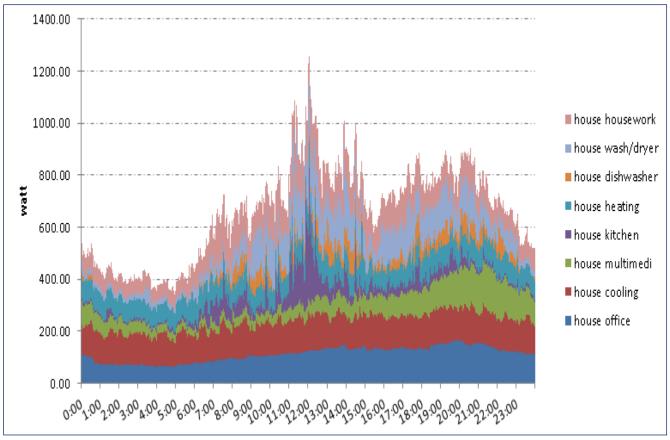


Figure 57: impact of type of building on usage pattern of appliances (detached house)

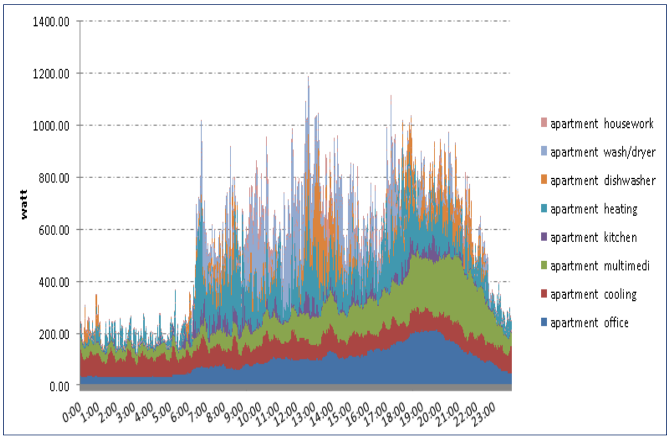


Figure 58: impact of type of building on usage pattern of appliances (apartment)

For example when the people are not at home most appliances will not be in use. Only appliance, which have low correlation to people's habit like cooling devices and appliances in standby mode, are consuming energy during the night. The family members may wake up and prepare breakfast and related to their job situation vacate or half vacate the house during the morning and then return around mid-day for lunch, in the evening the household’s activity will continue, etc. the different households has different life styles. Since we do not have any information about occupancy pattern of households, we extract the data from usage pattern of devices. The devices will get in use when the people are at home. In this regard, different family types defined in chapter 3 (see Figure 11: sample classification) can be used as input parameter. Defined family types are based on job situation and number of household members and can provide enough information about occupancy time of dwelling and likelihood of using household devices during a day.

4.4. Stochastic bottom-up Markov chain model

Analyzing the power consumption of each device shows that consumption in each state is strongly correlated to the preceding state. It gave us the idea of using Markov chain model to simulating the usage pattern of the devices.

The total load profile shape will of course vary from day to day and house to house. It is important to identify the cluster of households when analyzing the load profile, because the load profile depends very much on the occupancy pattern or rather the usage pattern of electric devices. In this case, we use the classified family type, which has been discussed before. Day and season type will be considered separately.

Precise analysis of measured energy consumption in households reveals that despite of macro scale typical cyclic similarities like morning and evening peaks, small base load over a night, lower consumption over weekend and sine curve seasonal changes in energy consumption, dwelling load profile in micro scale is a stochastic function based on random presence of switched electric devices in building.

There are two types of factors, which are influencing the usage pattern of household electric devices, deterministic and nondeterministic.

Periodic changes in the type of days over a week or seasons over a year, accounts as deterministic parameters, which are not altering randomly and have considerable influences on the usage pattern of household appliances. Family type, which has been introduced in first part of study, also accounts as a deterministic factor for the occupation time of the building (house / apartment).

In order to simulate household load profiles considering all influencing factors, it is necessary to make a cluster analysis [67]. Figure 59 represents implemented clusters based on deterministic factors.

Load profile in each cluster is composed of stochastic operation of household devices that are influencing by type of day and seasonal effect.

Although some household devices like refrigerator and freezer are cyclic devices and their operation are mostly dependent to outside temperature but they are not completely independent from behavior of households.

How often the door of cooling devices is open and how hot the staff inside the cooling devices are, influence the operation of compressor and its energy consumption.

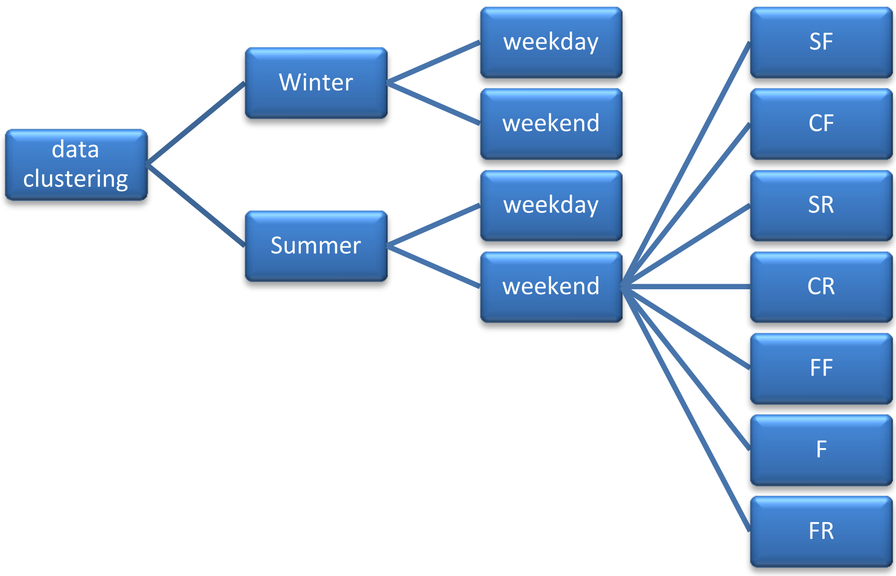


Figure 59: Scheme of data clustering

Since user behavior, plays an important role in switching household devices on/off and regarding unpredictable nature of user behavior, load profile can be describe as a stochastic process.

Markov chain is a method for generating sequences of random numbers to reflect stochastic probability distributions [68], [69], [70]. In particular, it is suited to model systems where the current state of a sequence is highly correlated to the state immediately preceding it and where a large sample size of data exists (see Figure 60).

In households availability of people at home and consequently usage of electrical devices in each time state (second/minute) is highly correlated to the last state.

For example if in one given household a coffee machine is switched off at 6:00 a.m. it is very likely that it will keep switched off the next minute. The calculated probability based on database is 0.9943. Alternatively, if coffee-machine is switched on at 6:00 a.m. then it is most probable that it will stay switched on in the next minute as well. Table 7 gives an example of transition probability matrix for coffee-machine.

Table 7: example of transition probability for coffee machine

Status of coffee machine	Next state (at 6:01 a.m.)	
Current state (6:00 a.m.)	0	1
0	0.9943	0.0057
1	0.2	0.8

This concept would be repeated for each device and for each minute intraday but the probabilities are going to change according to time of day.

To generate power demand data for a household, the model proceeds in four main steps as outlined in Figure 61. Synthetic status vector is generated for each household device in the first step. After applying a correction filter in order to modify the status of cyclic devices in step two, status vectors are then converted into power demand for the household appliances in the third step. Aggregation of converted synthetic status vector of household devices leads to produce load profile of a household in step four. This procedure can be repeated for an arbitrary number of households to create a larger set of demand data.
Input data to the model are classified cluster data like season, day and family type. Markov chain transition probabilities that determine status vector for household appliances and household appliance power consumption, which is obtained from measurements, are needed parameters for load profile simulation.

The transition probability varies with time to produce diurnal fluctuations. The Markov chain process described by transition probabilities is thus the non-homogenous as compared to homogenous process where the transition probabilities are fixed.

In the Markov chain model, it is assumed that a device can function in one of two states: (1) ON, (2) OFF. Although standby mode exists in the database for each device, it is considered that ADRES households' electrical appliances have no standby energy consumption and state (3), standby mode, has been ignored in Markov chain model.

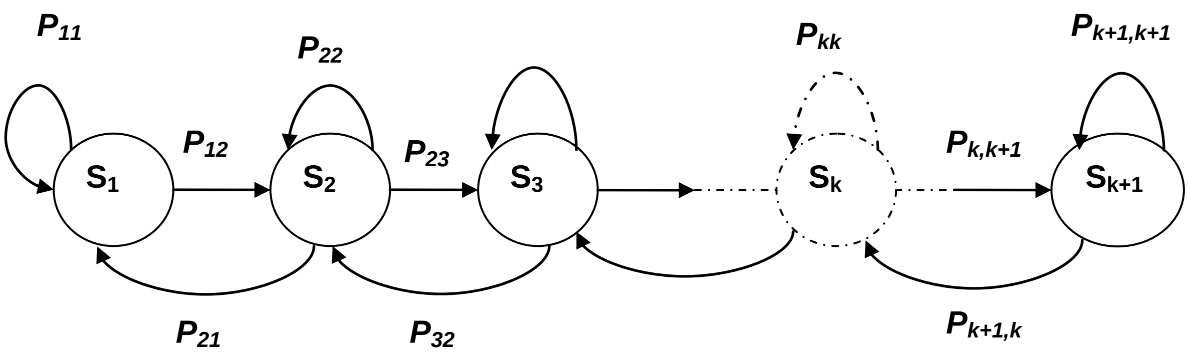


Figure 60: Markov chain principle

Each device must get one of these states in every discrete time step T=1,...,k+1.

It is further assumed that when switching from time step k to k+1 there is a so called transition probability $P_{k,k+1}(t)$ of going from state K to K+1. Obviously, $P_{kk}(t)$ is the probability for staying in the same state as it was before. Transition probabilities can be straight forwardly calculated from measured data. It is supposed that series of measured data for N devices, showing whether the device is in function in every given time step t=1;...;N.

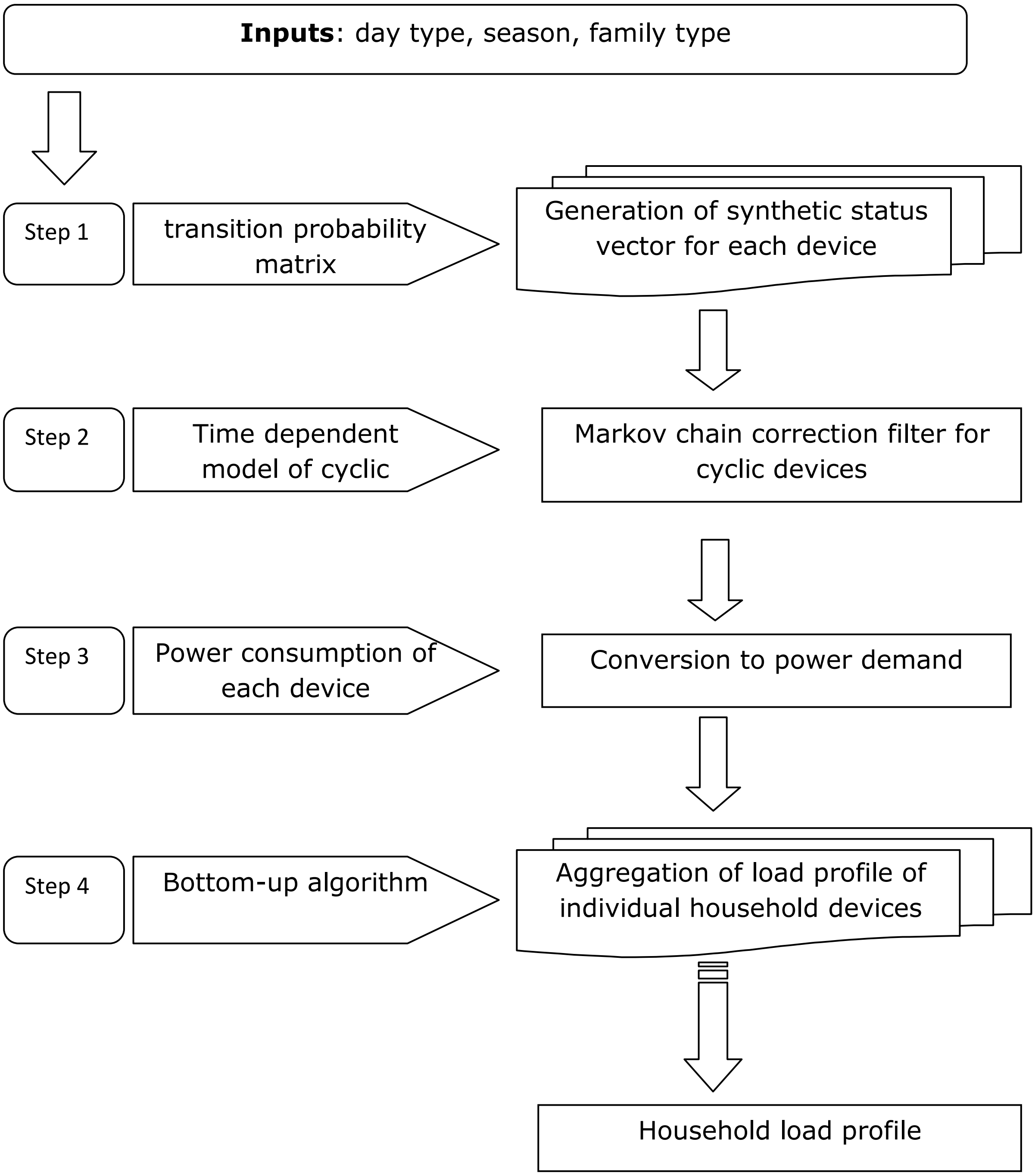


Figure 61: schematic depiction of the model used for load profile generation

All N transitions between time steps k and k+1 are examined and the total number $n_{k,k+1}(t)$ of transitions between states k and k+1 are determined. The total number of changes from state k is then

$$n_k(t) = \sum_1^N n_{k,k+1}(t) \quad (1)$$

N is the number of available measurements

and the transition probability estimate is:

$$P_{k,k+1}(t) = \frac{n_{k,k+1}(t)}{n_k(t)} \quad (2)$$

In order to generate the Markov chain, it is necessary to provide a start state: for example, how many washing machines are in function across the measured households among the measuring duration at 00:00. This is of course random but it should match the probabilities found in the original TUS data.
Given a complete set of transition probabilities, a realization for one device can be made by assuming an initial state, generating a uniform random number in each time step and comparing this with the transition probabilities to determine which transition is taking place. This is formulated in the following algorithm that generates a series of functioning data.

Transition probability matrices have been calculated for weekday and weekend in summer and winter. Separate treatment of detached, semi-detached and apartments has been ignored because of lack of data, but house type is considered for classified family types.

The proposed model for simulating domestic demand load profile is based on classified family type and pattern of energy use of individual electric appliances. Patterns of energy use of the appliances are generated with a two-state non-homogeneous Markov chain, with transition probabilities determined from a detailed set of date base in measured households.

The transition matrix is calculated for each device in each family category.

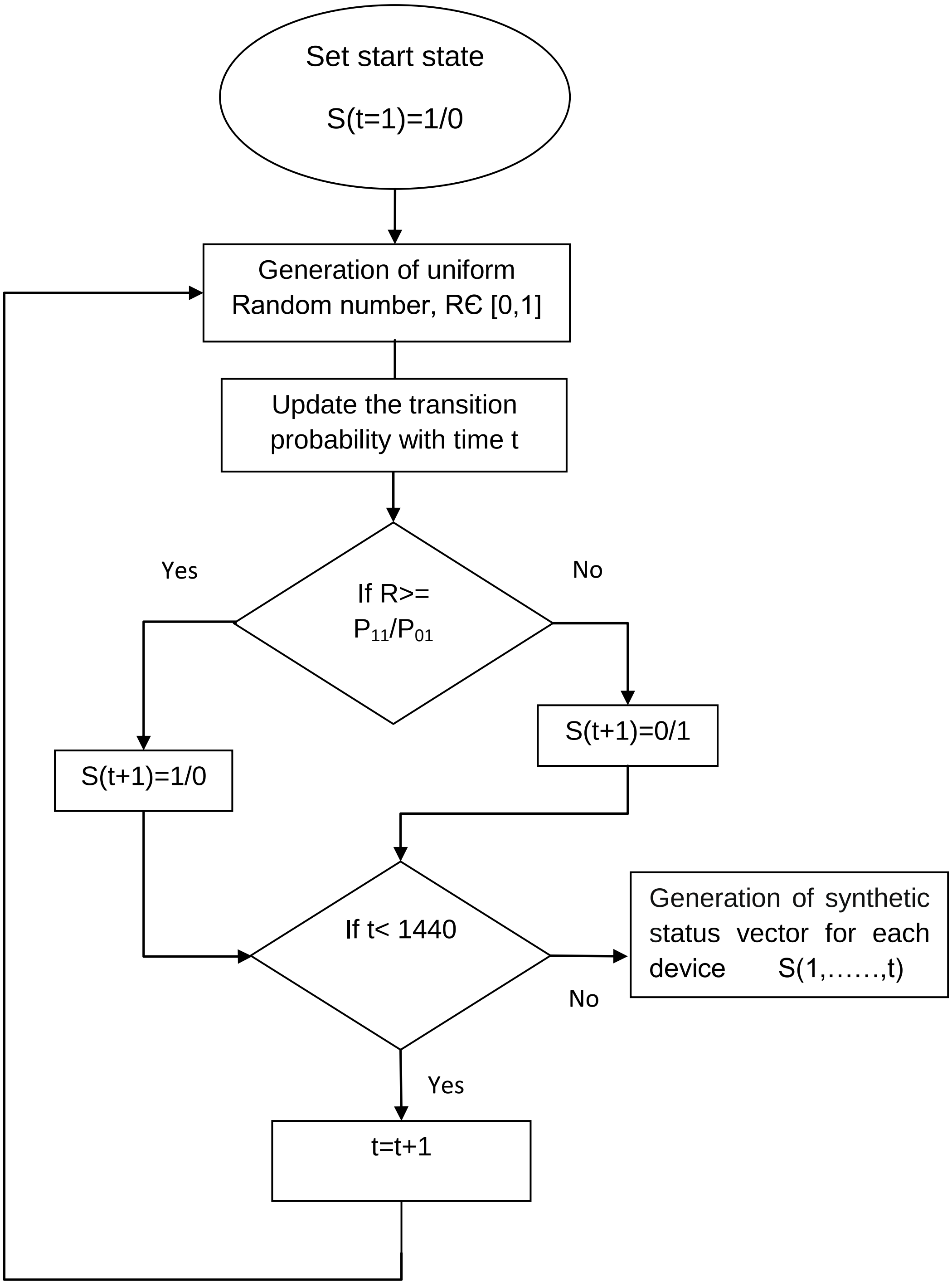


Figure 62: flowchart diagram of Markov chain model for producing synthetic status vector

In order to generate the synthetic data, a random number uniform distributed from 0 to 1, is picked up in each time step and used together with appropriate transition probability matrix and the state at the current step time to determine the state at the next time step (see Figure 62).

One of the unique features of this model is that each individual device is accessible in the model. In the case of simulated grid frequency, demand response is observable.

Before converting the synthetic status vector of each device, it is necessary to make the usage pattern of cyclic devices corrected. Some devices are represented by time varying demands. For example, a dishwasher which functions through various stages of water heating, washing, spraying hot water at dishes, rinsing and drying, significantly varies its demand throughout the cycle. In order to obtain a qualified load profile, a filter function has been written in MATLAB to rectify the cyclic devices.

4.5. Results

An example simulation for all defined family categories, for a winter weekday (wdw) and weekend (wew), is shown in Figure 63.

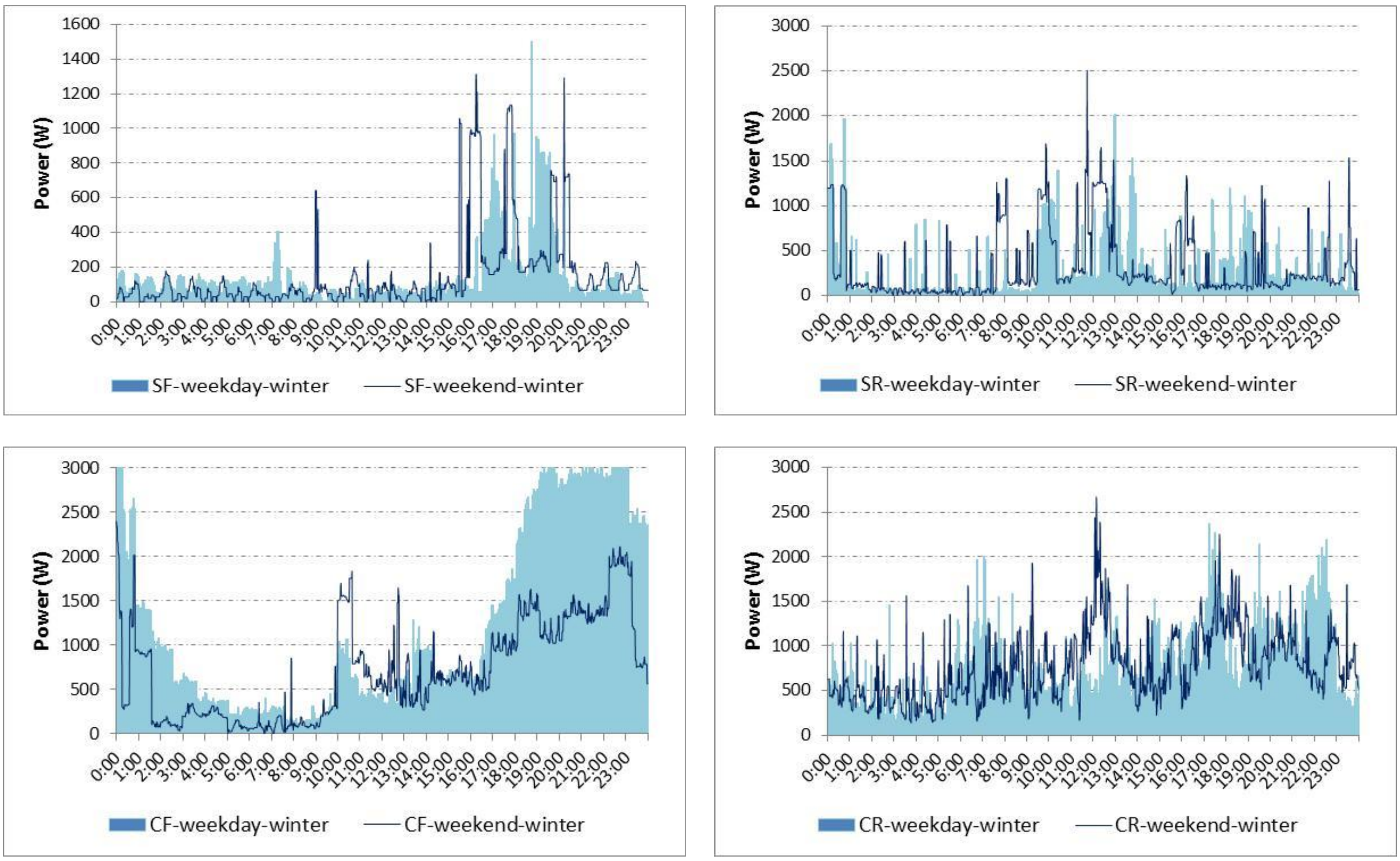
In this example for showing a representative winter day, simulation has been done five times and the average of these five days has been represented in the below figures. As is typical of such profiles, there is no activity at night except presence of electrical heating in some households.

According to categorized family types, which was based on occupants job and household's member number, load consumption in simulated profiles also occurred in the supposed times. Considerable differences between weekend and weekday's load profile can be recognized easily from the figures.

Changes in the amount and time of power consumption during a typical weekday and weekend show first general validation of the results.

For example in Figure 63, SF shows the simulated load profile of a single family house. The filled surface depicts a weekday and continues line presents a weekend profile. It is clear that during working day breakfast peak happens earlier around 7:00 and in weekend it will be shifted to later time like 9:00. Although SR is related also to a single-family house but retired one, there is no likelihood between SR and SF pattern. It is manifested, that not only the number of household member but also the occupancy pattern of a house are significant factors in order to develop electric load profile.

Increasing the number of people and life style cause to have more various devices and fluctuation of profile is going to increase. CF, CR, FF and F are couple fulltime, couple retired, family fulltime and family with one parent at home respectively and example for fluctuated load profiles.



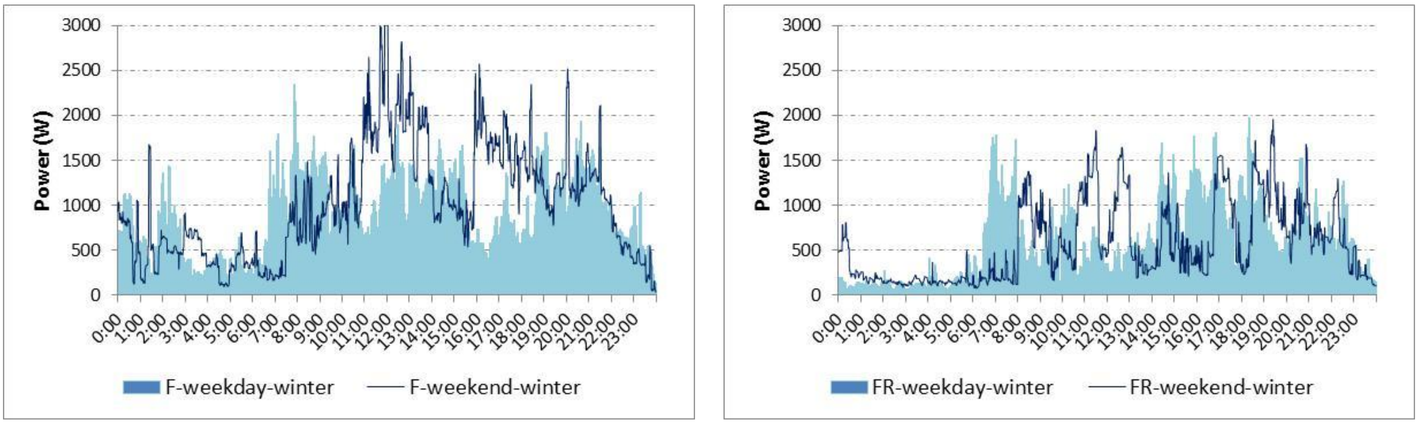


Figure 63: simulated daily load profiles for various family types

In the above figure, FF and F diagrams also depicts nicely when family members have fulltime job, lunch peak is not very visible and energy consumption starts again around 16:00 o'clock when people are coming back home. When one parent is at home, rate and time of consumption varies intraday and some home activities, which need electricity like ironing, sewing, cleaning using vacuum cleaner, etc. is running during day.

For making the result of model validated, it is necessary to compare the result of model with a reference pattern. In this regard, standard load profile (SLP) which is used by utilities is the best available reference.

Since SLP is a normalized averaged aggregated profile, comparing the result of simulated individual households will not give us possibility to validate the proposed model. In this regard, a domestic settlement has been defined [ADRES project] and the load profile of this defined settlement has been calculated with the proposed model. Now total load profile of the defined settlement can be validated against SLP.

4.6. Case study and validation

Ideally, the modeling framework presented in section 4.6, should be validated against standard dwelling load profile using in utilities (H0-load profile).

In this regard, it is decided to define an arbitrary settlement and use the developed model in order to simulate the load profile of the settlement. Proportion of various family types in the settlement are calculated, based on ratios in Statistic Austria. Table 8 presents the number of different family type in ADRES settlement, which is compared on distribution of family types in Austria.

Table 8: distribution of various family sizes in ADRES settlement

persons/ HH	proportion of family types in Austria (%)	Number of HH in ADRES
1	35	70
2	28	57
3	16	32
>=4	20	41
sum	100	200

On the other hand, not only the number of household's member but also their configuration is important. Job situation is a significant parameter to make family clustering. Based on the distribution of defined family types in conducted survey (see Figure 11) calculated number of household from above table is converted to defined sub categories.

Table 9: final family clustering in ADRES settlement

Family type	Job situation	No. HH
Single	Full-time	25
	Retired	45
Couple	Full-time	12
	Retired	45
Family	With full-time parents	19
	With just one full-time parent	37
	With retired member	17
Sum		200

4.6.1. Simulation of daily pattern of electric demand

From now on all the simulations have been done for the ADRES settlement with 200 households and defined family types mentioned in Table 9. In Figure 64, the red line presents the total load profile of settlement for different weekdays and seasons. The blue line represents the standard load profile, which is developed, based on the household's normalized standard load profile (H0) and average yearly energy consumption of defined family types. Comparing the result of the simulation model with the household standard load profile (H0) this indicates a high correlation in the shape and average amount of power consumption of load profile. As it is expected, simulated load profile has fluctuating changes in the power consumption in each minutes while the standard load profile is changing smoothly.

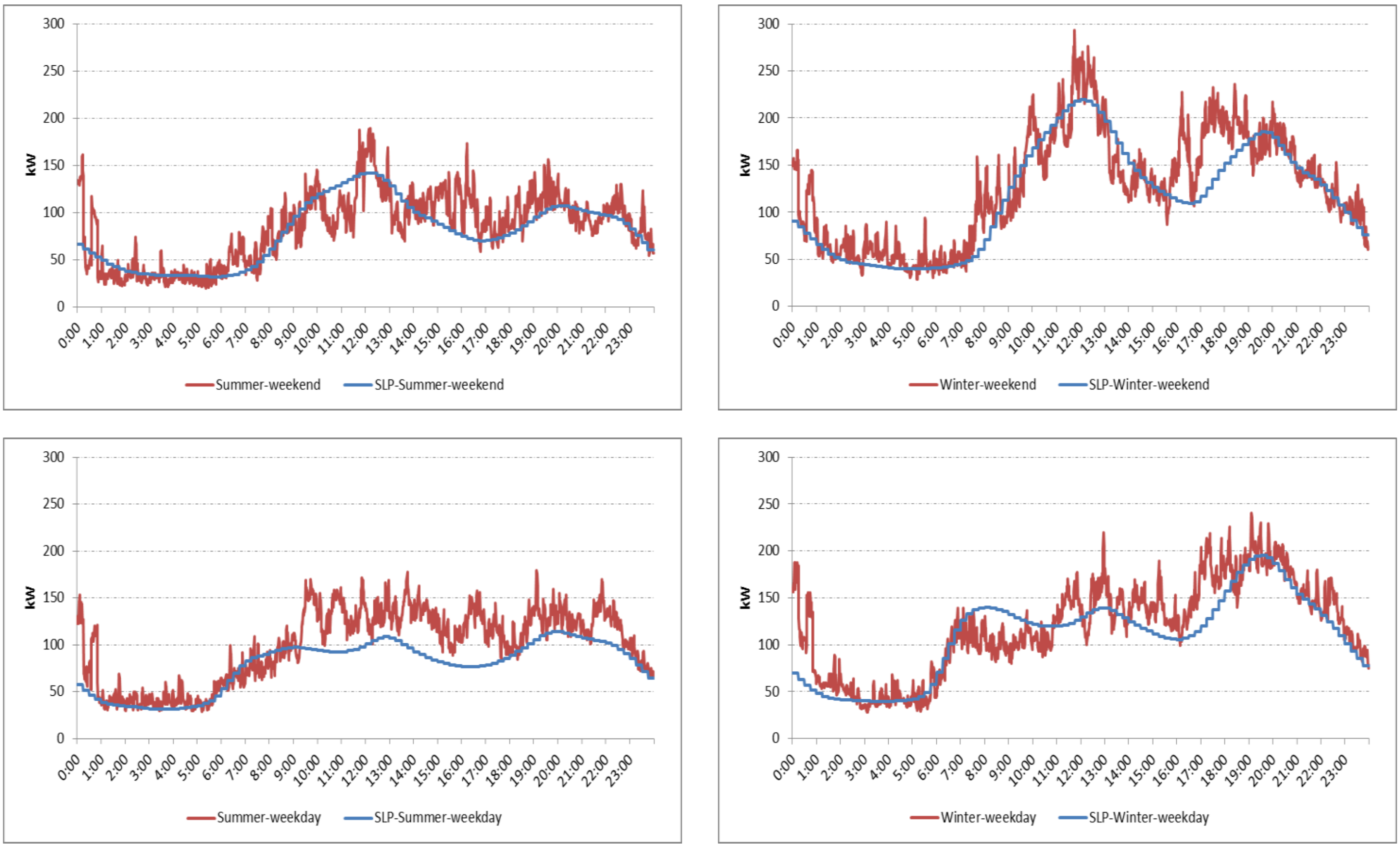


Figure 64: simulated daily load profile for ADRES settlement split in season and weekday type

Since the standard load profile is not including the energy consumption of heating devices, the heating category is also excluded from the simulated load profile in order to make the validation comparable.

Thus, the daily simulation of load profile using stochastic Markov chain model is validated and it is ready to be used in early design of micro grids.

4.6.2. Simulation of annual energy demand

For assessing the annual energy demand of settlements, the simulation model has to run through 365 days for each family type.

$$E_{annual}(kWh) = \sum_{u=1}^{356*24*60} P_{min,u}(W) \Big/ 60 \quad (3)$$

In addition, based on measured data, the annual energy demand has been calculated.

$$E_{annual}(kWh) = 140 * E_{wtw} + 55 * E_{wew} + 123 * E_{wts} + 47 * E_{wes} \quad (4)$$

E, E_{wew}, E_{wts} and E_{wes} are averaged daily energy consumption of measured households in winter and summer split in weekdays and weekends.

Merging the transition period into summer and winter, lead to have roughly 140 working days & 55 weekends in winter and 123 working days & 47 weekends in summer.

On the other hand, Statistic Austria published in 2008 data about the average annual energy demand of households according to their family size. All mentioned data are gathered in Figure 65.

Some differences between statistic, calculated and simulated data have been observed. Likely reasons for depicted differences are listed below:

1- Number of observed households in measurement campaign including different family categories is not statistically representative. The results reveal that increasing the number of observe data will enhance the output result visibly.
2- Statistic data is based on the size of households and there is no information about defined family categories. Based on number of different family sizes in observed family categories a relevant amount of energy demand has been calculated.
3- Annual energy consumption of measured households has been calculated based on summer and winter values over roughly 10 days. That is why information of transition period has been dismissed.
4- Simulated data are based on measured data and not all available devices were measured, partly because of lack of measuring sensors in the households and sometimes according to fixed installed devices like electric range.
5- Standby demand was not included in the simulated demand.
6- Assuming passive house as future house and relevance of heating, ventilation and lighting energy demand to the type of house, lighting energy demand was not considered in the simulation model.

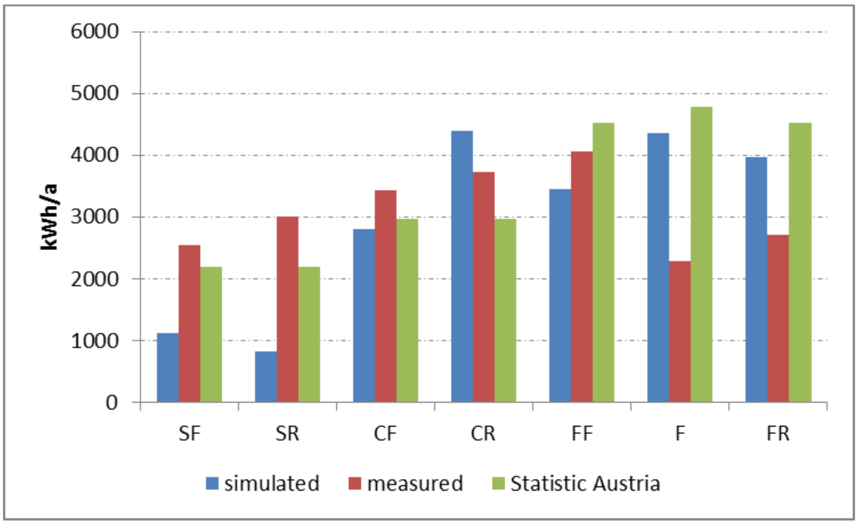


Figure 65: simulated, measured and national annual energy demand

Beside total energy demand, annual demand of individual devices also compared with counterpart measured and statistic data (see Table 10).

Two additional reasons, cause simulation errors in annual energy demand of households:

1- dismissing the weekly period factor for cyclic devices cause like washing machine, dryer and dishwasher
2- Regarding long simulation time, annual simulation has been done just for one household in each family category

For cooling devices, the maximum simulation error is roughly 25% and for cyclic devices, it is above 50%.

Table 10: simulated, measured and national energy consumption of individual appliances

	No. of obserevd households		refrigerator	freezer	dishwasher	dryer	washingmachine
SF	1	simulated	228	167	19	0	119
		measured	340	286	4	7	64
		statistic Austria	236	137	57	19	79
SR	2	simulated	228	167	19	0	119
		measured	228	159	113	39	458
		statistic Austria	236	137	57	19	79
CF	1	simulated	232	182	221	84	107
		measured	308	227	87	25	422
		statistic Austria	299	180	147	38	163
CR	11	simulated	317	346	157	294	295
		measured	449	304	188	103	326
		statistic Austria	299	180	147	38	163
FF	5	simulated	474	275	205	137	518
		measured	439	405	714	129	332
		statistic Austria	320	296	222	91	237
F	14	simulated	488	195	167	662	389
		measured	364	265	205	68	200
		statistic Austria	290	267	319	176	249
FR	4	simulated	312	294	177	220	457
		measured	743	430	100	54	388
		statistic Austria	320	296	222	91	237

Since the aim of simulation tool is to simulate daily load profiles for early stage design of micro grids, imperfection of model in estimating the annual demand will not change its ability to simulate daily profile.

Chapter 5

Demand Frequency response

5.1. Background

Spinning reserve is the most important resource, which system operators use when a generator goes down or in a case of another disruption to the supply. The purpose of reserve resources in the electricity grid is to keep the security and the quality of the generated electricity.

In conventional power system, generator units are in charge of providing spinning reserve in order to make primary, secondary and tertiary control, applicable in the unbalanced system.

In the event of a large load variation, for example in a case of power plant failure or other unexpected supply or consumer changes in the European transmission and interconnected system (ENTSO-E network), the individual system operator help out with primary control, which almost instantaneously available [71].

If it is a short deficit performance or a short power surplus, primary control itself can overcome the instability of the system. The primary control is defined as an automatically becomes effective restoration of balance between production and consumption which should be acted within 30 seconds after fault occurrence. In case of a longer shortage of generation, after a defined time (up to 30 sec), or already parallel to the primary control, the secondary control system will be activated to allow the primary control be relieved in order to provide the previously described function. In contrast to the primary control, which ensures stable frequency in transnational area, the secondary system is responsible for balance of power deficit or surplus within the control areas. If the power deviation takes longer than 15 minutes, the secondary system will be replaced either automatically or manually by the tertiary system, or they can come in to the operation together.

Result of various studies show that electric demand can compete against generation side in order to provide spinning reserve. Electricity demand can be disconnected much faster than generation increased when the frequency drops in the electricity system (see [72] to [76]).

Based on uptake of renewable resources in energy system and their dynamic fluctuated nature, active control of electricity demand plays an important role in order to create a decentralized spinning reserve [78]. Using demand as a fast reserve is an alternative to conventional expensive reserves in the current electricity system.

Keeping the power balance between supply and demand has the highest priority in the operation of power systems. Frequency deviation, ascending or descending, in a power system is an indicator of balance or imbalance between production and consumption. If power demand exceeds supply in the system, frequency will drop and conversely, if supply power overtakes the demand, frequency rises. The system frequency fluctuates continuously in response to the changing demand and must be rapidly restored by using spinning reserves. In traditional power system, reserves are mainly provided on the generation side by including extra capacity of generators and interconnection lines.

In micro grids with non-dispatchable dominated supplies, reserves can be provided by using demand side frequency response support. Frequency response support of demand has several advantages such as fast responding speed, low costs and high dispersion at feeder level.

Using demand as spinning reserve is not a new idea, but was focused on large size industrial loads in the past. Domestic demand with small electricity consumption can also provide reserve, which was proposed as early as in 1979. The recent uptake of micro generation units makes the idea more attractive and motivates many researches in the field. Different studies claim that there are many sectors of demand in power system, which can play the role of spinning reserve.

In the following sections, result of investigation about interest of consumers in load shifting and result of demand side management (DSM) based on frequency response are discussed.

5.2. Potential of daily flexible load

In conducted survey among electricity customer in Austria, which has been investigated in chapter 3, respondents were asked to grade their flexibility in shifting the operation time of some household devices. The aim was to reveal, to which extent consumers will concur to shift their loads, including delay in the start time or intermediate interruptions during the operation of appliances. Figure 66 discloses acceptance level of people in shifting their washing machine, tumble dryer, dishwasher and electric range. Grades 0 to 4 describe high to low flexibility degrees respectively.

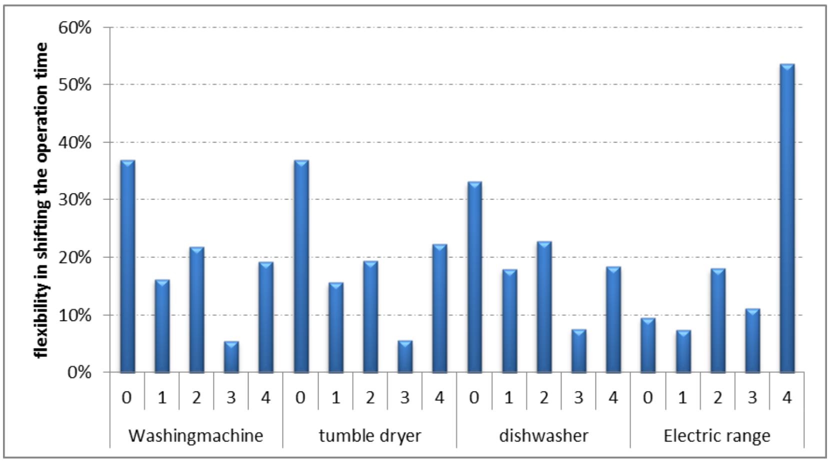


Figure 66: flexibility grade in shifting the operation time of devices

Analyzing the data from the survey shows flexible operation of devices is highly acceptable. Almost 60% of consumers have agreed to have flexibility in the operation of wet devices.

Electric ranges are, from consumer point of view, highly inflexible in changing the time of their operation. More than 60% of interviewees announced their inflexibility in way they use electric ranges.

According to the feedback got from respondents, which complies with other international studies [78], in addition to cooling and heating devices, which can be controlled un-intrusively, wet devices has been selected to assess the potential of disconnectable loads. Particularly, the thermostatically controlled loads such as heaters and refrigerators have cyclic on/off characteristic with considerable volume, which make them ideal to be used as frequency controlled reserve [72].

Based on result of this investigation and regarding to simulated daily profile, Figure 67 shows frequency of presence of demand versus proportion of total demand in a case of disconnecting the devices, which have higher shifting flexibility, in terms of total load demand.

For example, it is 70% likely within a day, that cooling devices can be disconnected and save 10% of total demand in each minute and the probability of disconnecting 20% of total load is 26%. There is a same interpretation for other devices in below figure.

Figure 68 gives the same information for luxury, entertainment, kitchen, homework and office appliances. Although switching devices in mentioned categories will disturb the normal requirement of customer but in emergency interruption for some seconds or minutes, it will prevent the energy system from facing blackout. Intensive bar lines in following diagram reveal high potential in shifting brown goods in emergency case. For reducing 5%~10% of the total load profile intrusively, there is a probability of more than 40% intraday.

Regarding to report of "demand as frequency controlled reserve" (see [80]) which was done with technical university of Denmark, the period of under frequency events are often very short. In less than 5% of the cases, the duration is more than 1 second. Applying demand response to demand intrusively or non-intrusively for disconnecting some loads for almost one second will save millions of Euro cost of blackout in electricity grid.

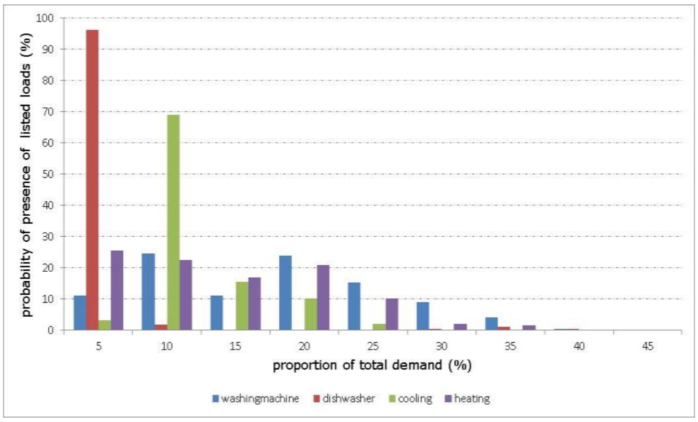


Figure 67: frequency of demand vs. disconnection potential of white goods

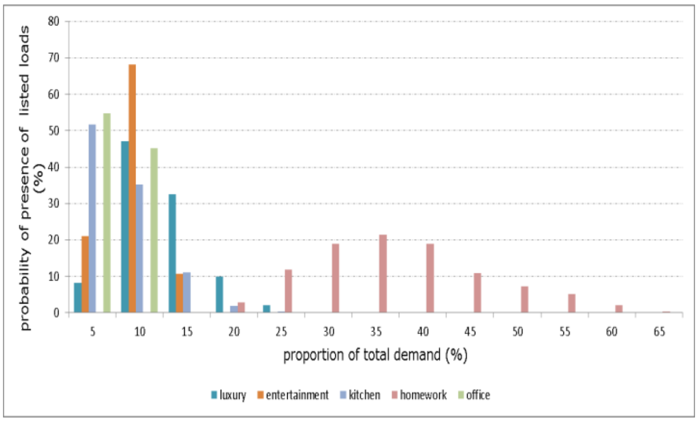


Figure 68: frequency of demand vs. disconnection potential of brown goods

Regarding Figure 69, in almost 30% of the time intraday, there is 30% to 35% of total load consumption available to be disconnected and reduce the consumption in a case of frequency drop and low available amount of generated energy.

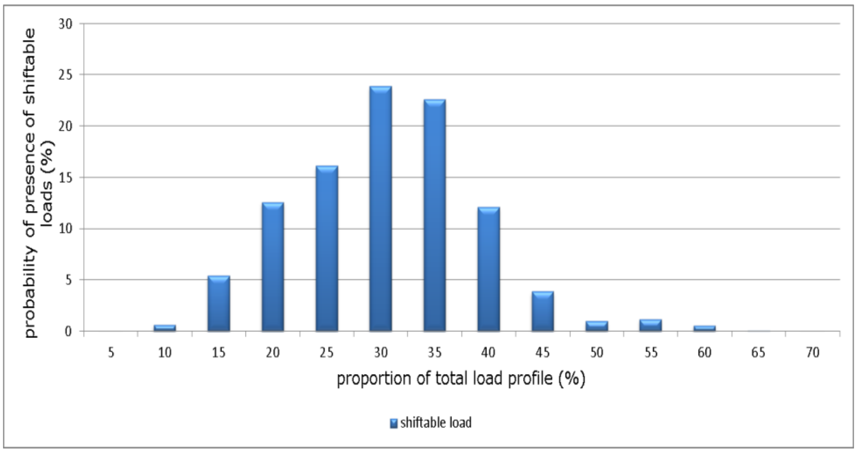


Figure 69: probable flexible load vs. proportion of total load profile

On the other hand, there are also potentials of connecting the devices to the grid in the case of higher available rate of renewable energies, consequently increasing the frequency rate. Based on installed devices in the ADRES settlement, the technical potential of switchable loads has been presented in Figure 70 to Figure 73 (Blue lines).

Potential of dis-connectable loads depicted with red lines and blue lines are presenting the potential of connecting flexible devices to the electricity grid.

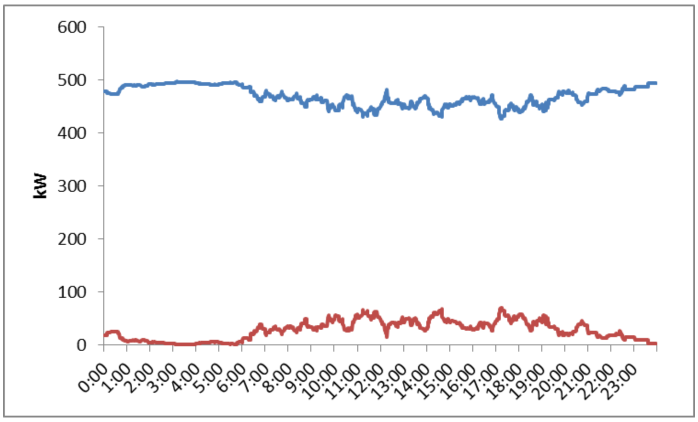


Figure 70: Technical potential of connectable(blue-line)/disconnectable (red-line) of washing machines

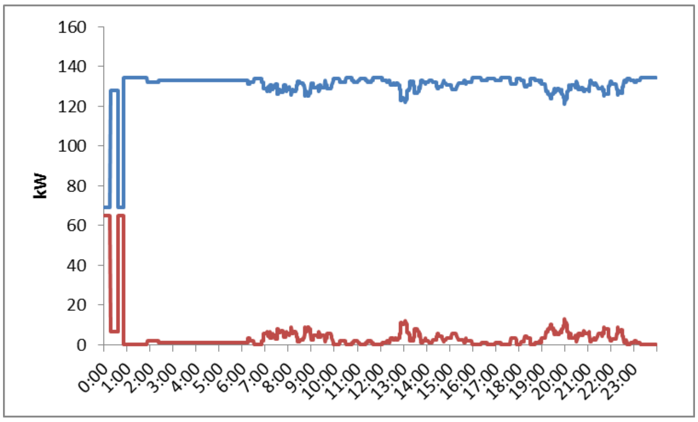


Figure 71: Technical potential of connectable(blue-line)/disconnectable (red-line) of dishwashers

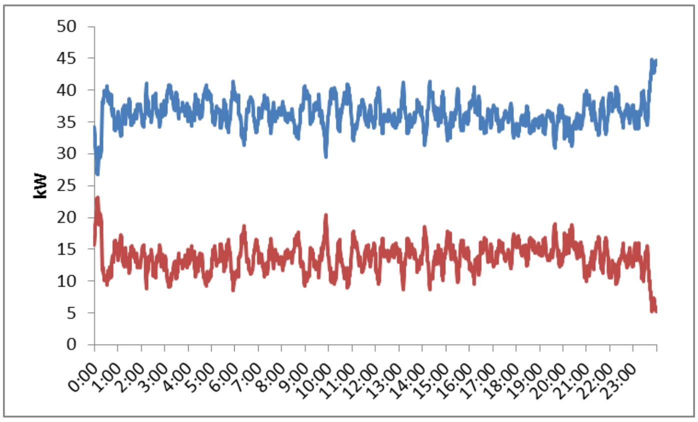


Figure 72: Technical potential of connectable(blue-line)/disconnectable (red-line) of cooling devices

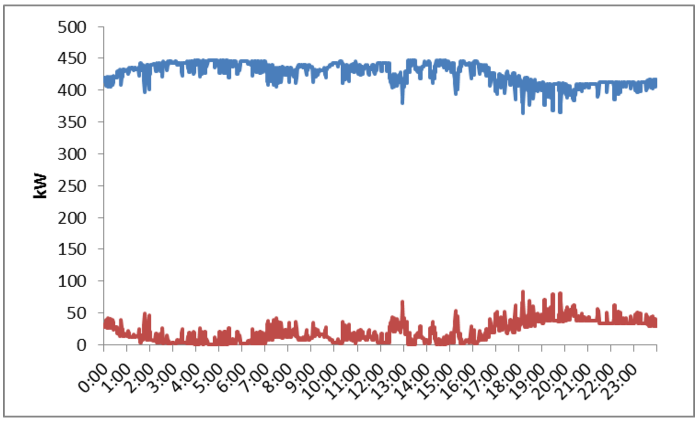


Figure 73: Technical potential of connectable(blue-line)/disconnectable (red-line) of heating devices

5.3. Demand side management (DSM)

Demand-Side Management (DSM) plays an important role in power system's regulation. In particular, DSM is the enhancement of consumer energy demand in order to make balance between energy production and consumption. DSM can be categorized in two groups of actions, which are well known as : energy efficiency (EE) and demand response (DR). Applying EE measures, designed to reduce electricity consumption during all hours of the year, as it is discussed in chapter 3 and DR, is an attempt to permanently reduce the energy demand in time intervals ranging from minutes to hours. DR can be based on different input signals like time sensitive price of energy, frequency of grid, etc.

There are various studies in order to assessing the effect of time of use pricing and dynamic pricing on the pattern of load profiles (see [81] to [84]). Although in micro grids, frequency is a significant factor to make system energy balance and is going to be used as input signal for DR.

This section is trying to describe the necessity of DR and the way it works. Last section presented the available potential of shiftable devices in the designed ADRES settlement. For being able to use the potential of flexible devices through shifting the time of operation within a day in a micro grid, household devices should be equipped with a frequency observation chip and related control system for switching the devices on/off properly in needed times. In other word, using smart and intelligent devices, which can follow the frequency deviations in real time, is necessary.

Since in this study no micro grid simulation has been done, it is not possible to bring the result of potential in demand frequency response to make demand side management scenarios. In order to solve the problem, it is assumed that frequency deviations are given artificially to the model and there are intelligent appliances in the ADRES settlement, which are able to response to frequency drift in any instant.

Figure 74 shows the result of DSM simulation. In the simulated case, a frequency drop occurs on 15:00 o'clock and will be removed after 15 minutes.

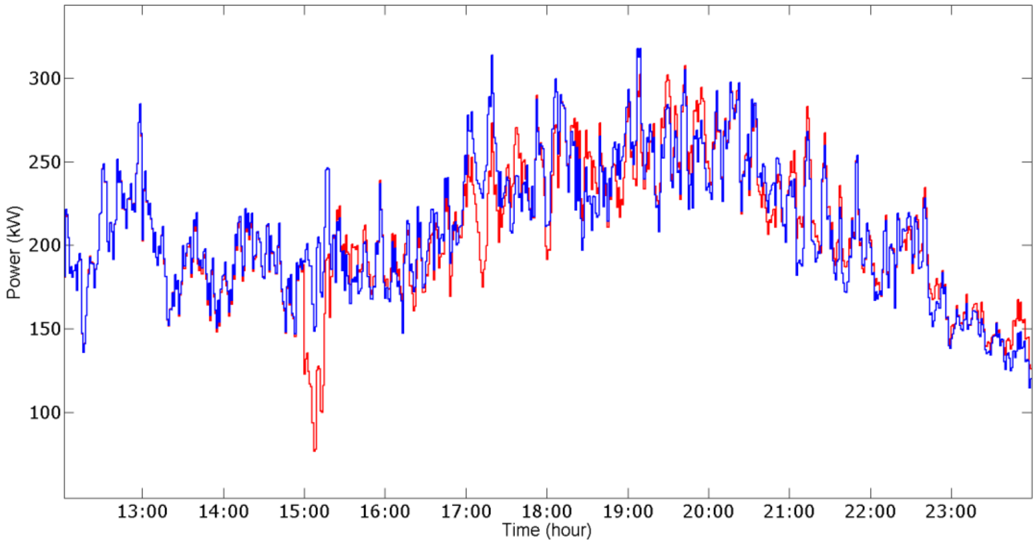


Figure 74: daily load profile before (Blue) and after (Red) deployment of DR

In order to have a better understanding on effect of DSM on the load profile, differences between load profiles before and after deployment of DSM have been depicted in Figure 75. Switching the available washing machines, dishwashers, cooling and heating devices simultaneously at 15:00 o'clock reduce almost 80 kW of energy demand in ADRES settlement. One problem that emerges after removing the frequency drop, is switching on all turned off appliances simultaneously again. This action will put many loads again in the system and cause instability in the grid's frequency.

In order to avoid instability in the grid after dismissing the flexible devices from the grid for a short time, devices will be back into the grid according to their state of charge (SOC).

SOC will be defined for cooling devices as available cold capacity for keeping the foods cold enough, for heating systems will be explained as heating capacity for making the water or room warm, and for wet devices will be assumed as the temperature of washing water.

The applied DR algorithm is based on the principle of a queue processing technique first in first served (FIFS). On the other hand, devices that have been switched off earlier will be switched on first after the grid got back to the stability point again.

Result of deployment of FIFS in DR algorithm is depicted in Figure 75 with clarity. Appliances that are switched off in the emergency are going to be connect to the energy system slightly without stressing the energy system with hug additional demand in the system.

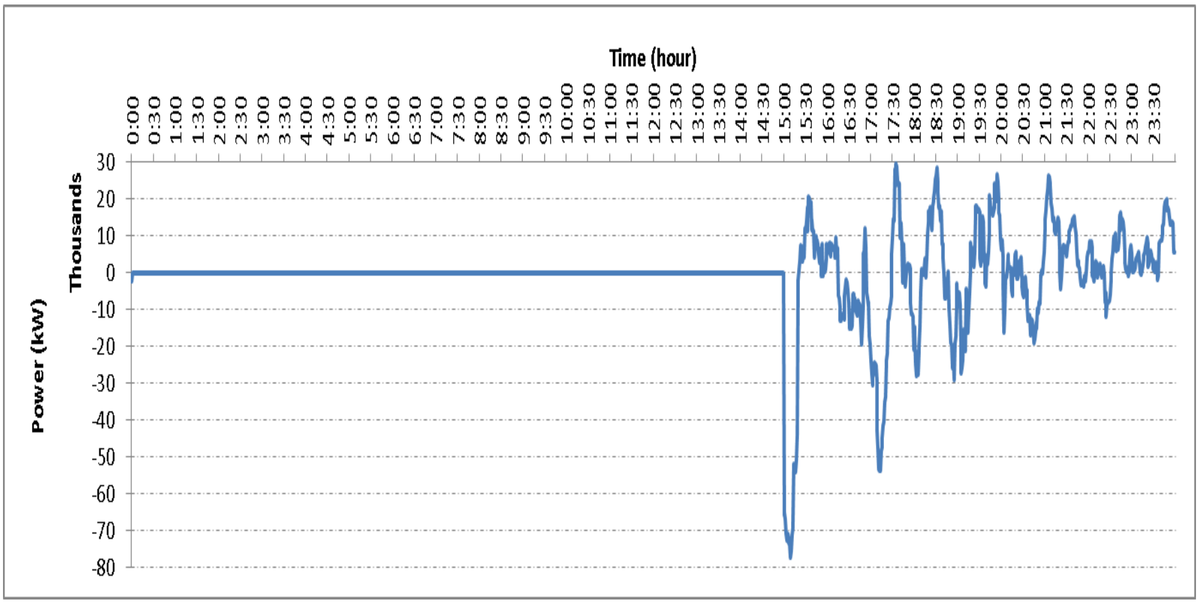


Figure 75: difference between load profile before and after application of DR

In the case of simulated micro grid, application of DR and energy system regulation can be simply applied to the system.

Chapter 6

Summary

6.1. Goals and contributions of this thesis

This thesis had the main goal of assessing the potential of energy efficiency and demand side management in micro grids. In particular, this research has been focused on the sector of households and household appliances, in the top of them white goods. The area of research is very broad but it has been concentrated to the core area, which is listed as following:

- Conducting a survey among electricity customer
    - investigation of household electric appliances and their energy classes
    - assessing the user behavior and its influence on total energy consumption and usage pattern of individual devices
    - estimating the energy saving potential considering the available energy directives and national energy action plans
- holding a measurement campaign
    - extracting the usage pattern of individual electric household devices
    - application of a bottom-up algorithm in order to simulate daily load profile
    - assessing the influence of DFR on the shape of load profile

In the first part, for proving the representative characteristics of sample, possible national data and available results of international studies have been compared to the gathered data.

To demonstrate the validity of proposed model, a domestic settlement with 200 households has been defined. The daily load profile based on season, day and family type has been simulated and standard synthetically load profiles have been developed for settlements with the same characteristics. The simulated load profile are in good correlation with the developed standard load profile.

Based on the proposed model, the effect of demand frequency response on the shape of load profile has been studied. The particular contributions and conclusions extracted from evaluations are presented in the next Sections.

6.2. Conclusion of thesis

6.2.1. Energy efficiency

The first objective of this work was to estimate the energy saving potential in micro grid with the focus on the household sector. In this regard, a survey was conducted among electricity consumers in Austria. Investigations on gathered data have been done, using cross sectional analysis methods. Except in the number of attendants in different family types, the gathered samples were in good correlated with the national statistical data. That is why further studies are based on results of sample data analysis. The age of household appliances, the frequency of their operation within a day or week, the time length of their operation, the penetration level of each appliance in household, the flexibility of consumer in changing their operation time and demographic information of family are the main extracted information from the sample data. Statistical analysis reveals that only by replacing the old inefficient white goods including TV with best available technologies in the market, will save in 2020, 2.6 TWh of energy.

Investigation of individual households declares that there is a saving potential up to 44% in annual energy consumption of households. Uptake of passive houses and consequently reduction of heating and lighting energy demand, “1 watt initiative”, will lead to considerable reduction of standby consumption. Introduction of A+++ energy class for white goods including TV and considering the efficient user behavior in the household sector are main reasons for energy reduction in annual household energy consumption.

It is obvious that without observing the energy efficiency measures on the behavior of users of household appliances on the one-hand and household’s appliance manufacturers on the other hand, energy system if future will face serious challenges. Since the positive effect of EE measures on white goods has been investigated, it is expected that by extending the energy labeling to the other household devices and deployment of other possible energy efficiency action plans lead to have secure energy system in future.

6.2.2. Demand frequency response

Second aim of this work was to simulate of daily load profile and analyze of effect of demand frequency response on the shape of load profiles.

Since gathered data via conducted survey was not enough for simulating the daily load profile, a measurement campaign was held in Austria in order to make investigation about time of use of each individual device, their usage pattern and the effect of family type on usage pattern of household devices.

Two types of measurement including the total daily energy consumption and energy consumption of available individual appliances in 1-second time resolution have been done for 40 households for almost two weeks split in winter and summer. A unique database has been prepared. Since the presence of people and their inclination of using electric household devices is a random process, a stochastic algorithm, Markov chain model, has been used for simulating the active time of individual household devices in clustered family types. Applying a bottom-up algorithm leads to calculation of total load profiles of settlements, based on load profiles of each individual household. One of the significant features of the proposed model is, that each device in each selected household is accessible in the model and with sending an on/off order signal the desired appliances will be connected to or disconnected from electricity micro grid.

In order to validate the result of the proposed model, a domestic settlement has been defined (ADRES settlement) and the daily load profile of the settlement has been simulated using the proposed model and is compared to the standard load profile, which is published every year with electricity utilities.

The results assured the validation of the model for simulating the daily load profiles based on the season and day type. Using the model for estimating the annual energy consumption of households or individual devices needs a more representative database in order to enhance the existing errors. After validation of simulated daily load profile and possible access to each individual appliance in households through load profile simulation, the proposed demand frequency response algorithm can be applied in order to make a feasibility study about available reserve capacity through dispatching energy demand.

Since there is no micro grid model in order to follow the frequency changes caused by fluctuation of micro generation units or load dispatching, the frequency drop was emerged and removed manually.

At given time, all flexible devices were dismissed from the energy system. Depending to the time of day, from 18% up to 71% of total load can be used as spinning reserve. Disconnected appliances were connected to the grid again after removing frequency drop. In the proposed algorithm in order to prevent the appearance of all disconnected appliances simultaneously and make a disturbance in the stability of grid frequency, the principle of queue processing, first in first serve (FIFS), has been deployed in which appliances that disconnected earlier will connect to the grid at first. Result of simulation reveals successful functioning of proposed algorithm.

6.3. Future work

Once finished this Thesis, there are several issues that remain opened related to simulation of daily load profile, application of demand frequency response and practical potential of shiftable appliances.

Although the proposed simulation model for generating daily load profile has been done successfully in this thesis, it needs detailed information about consumers energy consumption which is very costly. In this regard, a diploma thesis has been defined in order to disaggregate the high resolution total daily load profile into its components. This work is an ongoing thesis.

In order to investigate the effect of demand frequency response, dynamic simulation of household devices and micro grid is suggested. This proposed work has been initially started since the Author was doing a research internship period in Concordia University.

There is a considerable difference between technical and practical potential of shifting the time of operation of household device, which has not been studied in this work and can be continued based on result of this work.

References

[1] G.McInnes, E.Unterwurzacher, „Electricity end-use efficiency: An assessment of the scope for efficiency gains and policy options”, 1991, Energy Policy Volume 19, Issue 3, April, pp. 208-216

[2] International Energy Outlook, independent statistics and analysis US energy information and administration, 2010, http://www.eia.doe.gov

[3] A.Ilo, M. Reischböck, F. Jaklin, W. Kirschner, " DMS impact on the technical and economical performance of the distribution system", 18th International Conference on Electricity Distribution, Turin, 6-9 June 2005

[4] www.oecd.org, OECD fact book, 2009

[5] A. Adamantiades, I. Kessides, " Nuclear power for sustainable development: Current status and future prospects", 2009, Energy Policy, Volume 37, pp. 5149–5166

[6] T.M.Letcher, "Future Energy : improved, sustainable and clean options for our planet", 2008, Elsevier

[7] The EU climate and energy package, http://ec.europa.eu/clima/policies/package

[8] Brussels European Council 8/9 March , www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/93135.pdf, 2007

[9] Energy strategy Austria

www.bmwfj.gv.at/EnergieUndBergbau/EnergiestrategieUndEnergiepolitik

[10] Mass Market Microgeneration, www.microgenerationeurope.eu, 2010

[11] EU 25 Final electricity consumption by sector, www.eea.europa.eu/data-and-maps/figures/final-electricity-consumption-by-sector-1, 2010

[12] Gesamtenergiebilanz (1970-2009), www.statistik.at/energie_und_umwelt/energie/energiebilanzen, 2009

[13] national renewable energy action plans, ec.europa.eu/energy/renewables/transparency_platform, 2010

[14] The effectiveness of feedback on energy consumption, www.eci.ox.ac.uk/research/energy, 2006

[15] Austrian enerfgy efficiency action plans, ec.europa.eu/energy/energyefficiency, 2007

[16] M.Litzlbauer, " Generation of stochastic load profiles for mobile energy storages", 2010, 2nd European Conference Smart Grids and E-Mobility, Brussel

[17] R.Yao, K.Steemers, " A method of formulating energy load profile for domestic buildings in the UK", June 2005, Energy and Buildings, Volume 37, Issue 6, pp. 663-671

[18] S.Ghaemi, G.Brauner, "Potential of reducing the electricity demand in private sector", 10th Symposium Energieinnovation, TU-Graz, Austria, 13-15 Feb. 2008

[19] S.Ghaemi, G.Brauner, et al., " Dynamic Load Profile in ADRES project", 23th international power system conference, Tehran, Iran

[20] S.Ghaemi, G.Brauner, "User behavior and patterns of electricity use for energy saving", 6th International energy economics conference, TU-Wien, Austria, 11-13 Feb. 2009

[21] S.Ghaemi, G.Brauner, "Stochastic model for household load profile", 11th Symposium Energieinnovation, TU-Graz, Austria, 10-12 Feb. 2010

[22] S.Ghaemi, et. al. " ADRES@WORLD", The 21th international conference and exhibition on electricity distribution (CIRED), Frankfort, Germany, 6-9 June 2011

[23] A. Einfalt, G. Brauner, D. Tiefgraber, Ch. Leitinger, S. Ghaemi: "ADRES Autonomous Decentralized Regenerative Energy-Systems"; European Conference PV-Hybrid and Mini-Grid, Glyfada, Greece; 29-30 May, 2008, p. 514 - 521.

[24] A.Einfalt, C.Leitinger, D.Tiefgraber, S.Ghaemi, "ADRES Concept – Micro grids in Österreich",6th International energy economics conference, TU-Wien, Austria, 11-13 Feb. 2009

[25] L. Lutzenhiser, Social and behavioral aspects of energy use, 1993, Annual Review of Energy and Environment 18, pp. 247–289

[26] G.Wood, M.Newborough, "Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design", Energy and Buildings, 2003, Volume 35, Issue 8, pp. 821-841

[27] R.C. Sonderegger, Movers and stayers: the residents contribution to variation across houses in energy-consumption for space heating,1978, Energy and Buildings 1, pp. 313–324.

[28] T.M.M. Verhallen, W.F. Van Raaij, Household behaviour and the use of natural gas, Journal of Consumer Research 8 (1981) 253–257

[29] G.Wood & M.Newborough, "Dynamic energy-consumption indicators for domestic appliances: Environment, behaviour and design", 2003, Energy and Buildings, 35, pp. 821-841

[30] J.T. Van Houwelingen, W.F. Van Raaij, “The effect of goal setting and daily electronic feedback on in-home energy use”, 1989, Journal of Consumer Research 16, pp. 98–105.

[31] S. S. van Dam, C. A. Bakker, J. D. M. van Hal, “Home energy monitors: impact over the medium-term”, 2010, Building research & information 38(5), pp. 458– 469

[32] J.H.Broehl, "An End Use Approach to Demand forecasting ", IEEE Trans. on Power Apparatus and systems, 1981, Vols. PAS-100, pp. 27114-2718.

[33] C.F.Walker, and J.L. Pokoski, "Residential Load Shape Modeling Based on Customer Behavior", IEEE Transactions on Power Apparatus and Systems, 1985, Vol. PAS-104

[34] A.Capasso, et. al., "A Bottom-up Approach to Residential Load Modeling", IEEE Transactions on Power Systems No.2, 1994, Vol. 9

[35] Y.Shimoda, et. al., "Residential end-use energy simulation at city scale", Building and Environment, 2004, Vol. 39, pp. 959 – 967

[36] R.Yao, and K. Steemers, "A method of formulating energy load profile for domestic buildings in the UK", Energy and Buildings, 2005, Vol. 37, pp. 663-671

[37] J.V.Paatero, , and P.D. Lund, "A model for generating household electricity load profiles", International Journal of Energy Research, 2006, Vol. 30, pp. 273-290

[38] A high-resolution domestic building occupancy model for energy demand simulations. I.Richardson, et.al. pp. 1560-1566, s.l. : Energy and Buildings, 2008, Vol. 40.

[39] I.Richardson, et. al., "A high-resolution domestic building occupancy model for energy demand simulations", Energy and Buildings , 2010, Vol. 42, pp. 1878-1887

[40] D.G.Infield. ,"Potential for Domestic Dynamic Demand-Side Management in the UK", IEEE Power Engineering Society, 2007, Vol. General Meeting, pp. 1-6

[41] V.Hamidi, F.Li, F. Robinson, "The Effect of Responsive Demand in Domestic Sector on Power System Operation in the Networks with High Penetration of Renewables", IEEE Power Engineering Society , 2008, Vol. General Meeting.

[42] Bundesländern, Haushalte 2001-2050 nach Größe www.statistik.at/bevoelkerung/demographische_prognosen/haushalts_und_familienprognosen

[43] Haushalte nach Haushaltstyp bzw. -größe und Bundesländern www.statistik.at/statistiken/bevoelkerung/haushalte_familien_lebensformen/haushalte

[44] Ergebnisse im Überblick: Haushaltsprognose www.statistik.at/ statistiken/bevoelkerung/demographische_prognosen/haushalts_und_familienprognosen

[45] Gesamtenergiebilanz (1970-2009), www.statistik.at//energie_und_umwelt/energie/energiebilanzen

[46] Einspeisetarifefürnueökostromanlagen2010, www.e-control.at/konsumenten/oeko-energie/kosten-und-foerderungen/einspeisetarife-marktpreise

[47] S.Ghaemi, Fragenbogen zu Haushaltsstrombedarf. www.ea.tuwien.ac.at/download, 2008

[48] I. Mansouri, M. Newborough, D. Probert, “Energy-consumption in UK domestic households: impact of domestic electrical appliances”, Applied Energy 54 (3) (1996) 211–285.

[49] Ergebnisse im Überblick: Privathaushalte, www.statistik.at/bevoelkerung/haushalte_familien_lebensformen/haushalte, 2010.

[50] M.J. Brusco and S. Stahl, "Branch-and-Bound Applications in Combinatorial Data Analysis", 2005, Chapter 14. Variable Selection for Regression Analysis

[51] T.Hastie, R.Tibshirani, J.H.Friedman, "The elements of statistical learning: data mining, inference, and prediction", Springer, 2001

[52] P.D.Hoff,"A First Course in Bayesian Statistical Methods", springer 2009

[53] Chen, M.-H., Ibrahim, J.G., and Yiannoutsos, C. (1999), Prior Elicitation, Variable Selection, and Bayesian Computation for Logistic Regression Models, Journal of the Royal Statistical Society, Series B, 61, 223-242.

[54] Kuo, L. and Mallick, B.K. (1998), Variable Selection for Regression Models, Sankhy¯a, Series B,60, 65-81.

[55] Mitchell, T.J. and Beauchamp, J.J. (1988), Bayesian Variable Selection in Linear Regression (withdiscussion), Journal of the American Statistical Association, 83, 1023-1036.

[56] W.Mert, J.Suschek & W.Tritthart, Smart Domestic Appliances in Sustainable Energy Systems, working package " Consumer acceptance of smart appliances", Intelligent energy Europe program

[57] www.energystar.gov/ Explore Products >find energy star products->Displays

[58] T.M.I. Mahlia, et.al., "A Literature Review on Energy Efficiency Standards and Labels for Household Electrical Appliances", ASEAN journal on science and technology for developement, 2001, Vol. 18.

[59] 94/2/EC. http://ec.europa.eu/energy/efficiency/labelling

[60] 2003/66/EC. http://eur-lex.europa.eu

[61] 2010/30/EU. http://eur-lex.europa.eu

[62] 95/17/EC. http://eur-lex.europa.eu

[63] 97/17/EC. http://eur-lex.europa.eu

[64] http://www.en.bmwfj.gv.at/Energy/EnergyEfficiency

[65] Gesamtenergiebilanz (1970-2009) www.statistik.at//energie_und_umwelt/energie/energiebilanzen

[66] A.Wright, S.Firth, "The nature of domestic electricity-loads and effects of time averaging on statistics and on-site generation calculations", applied energy, 2006, Vol. 84.

[67] E.C.Bobris, et.al., "Clustering Techniques in Load Profile Analysis for Distribution Stations", Advances in Electrical and Computer Engineering , 2009, Vol. 9.

[68] D.Gamerman. Markov chain Monte Carlo, 2006

[69] M.H. Chen, et.al., "Monte Carlo methods in Bayesian computation", springer, 2002.

[70] Berg, Bernd A. Markov chain Monte Carlo simulations and their statistical analysis. s.l. : worl scientific, 2004.

[71] Ausgleichsenergie www.e-control.at/de/marktteilnehmer/strom/strommarkt/ausgleichsenergie

[72] Q. Binh Dam, S.Mohagheghi, J.Stoupis, "Intelligent Demand Response Scheme for Customer Side Load Management", IEEE Energy2030,Atlanta, GA USA,17-18 November, 2008

[73] V.Hamidi, F.Li, F.Robinson, "Demand response in the UK's domestic sector", Elsevier, electric power system research, August 2009

[74] J.Torriti, M.G.Hassan, M.Leach, " Demand response experience in Europe: Policies, programmes and implementation", May 2009

[75] N. Gudi et.al., " Demand Response Simulation Implementing Heuristic Optimization for Home Energy Management", North American Power Symposium (NAPS), Sept. 2010

[76] S.Shao, M.Pipattanasomporn, S.Rahman, "An Approach for Demand Response to Alleviate Power System Stress Conditions", IEEE Power & Energy Society General Meeting, 24-29 July 2011

[77] C. Marcus-Moller, "Demand as frequency controlled reserve-Analysis of technology and potentials", student project report, Technical University of Denmark, 2006.

[78] B.J.Kirby, "Spinning reserve from responsive loads", Oak Ridge National Laboratory, ORNL/TM-2003/19, 2003

[79] Z. Xu, J. Østergaard, M. Togeby, C. Marcus-Møller, "Design and Modelling of Thermostatically Controlled Loads as Frequency Controlled Reserve", IEEE Power Engineering Society General Meeting, 2007,pp.1-6

[80] Demand as frequency controlled reserve, final report of PSO project,www.eaenergianalyse.dk/electricity_demand_as_frequency_controlled_reserve.html

[81] C.Aubin, D.Fougere, E.Husson, & M.Ivaldi, "Real-time pricing of electricity for residential customers: Econometric analysis of an experiment", Journal of Applied Econometrics, 1995, volume 10, pp. 171–191.

[82] S.Borenstein, M.Jaske & A.H.Rosenfeld, "Dynamic pricing, advanced metering, and demand response in electricity markets", Sep. 2002, In Energy series: A Joint Project of the Hewlett Foundation & the Energy Foundation, California Energy Commission & the UC Energy Institute, San Francisco.

[83] A.Faruqui, K.Eakin, "Pricing in competetive electricity market", Chapter 22: "Residential TOU price response in the presence of interactive communication equipment", 2000

[84] D.W.Caves, L.R.Christensen, & J.A. Herriges, "Consistency of residential customer response in time-of-use electricity pricing experiments", 1984, Journal of Econometrics, Volume 26, pp. 179–203.