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Scenarios and Use Cases for the Energy Aware Smart Home

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Kurzfassung

Das Thema dieser Arbeit umfasst die Anwendungsmöglichkeiten von Hausautechnik in privaten Haushalten, oftmals auch *Smart Home* genannt. Durch den stetig steigenden Strombedarf von privaten Haushalten wird dieser Bereich, der bis jetzt eher in Bürogebäuden Anwendung fand, auch für den privaten Gebrauch interessant. Eine sorgfältige Evaluierung der Anwendungsmöglichkeiten und ihrer Zweckdienlichkeit muss untersucht werden. Vor allem die erweiterten Möglichkeiten, die der Einsatz von optimierten Kontrollsystemen basierend auf künstlicher Intelligenz in diesem Sektor bietet, werden eingehender Prüfung unterzogen.

Zu allererst wird der Begriff des *Smart Home* näher definiert und ebenso welche Kriterien solch ein Gebäude erfüllen muss. Neben einem groben Überblick über aktuell verfügbare Kontrollnetzwerke werden auch gegenwärtige Probleme und Herausforderungen beleuchtet, die einen großen Durchbruch dieser Technologie zurzeit noch behindern. Im Hauptteil der Arbeit werden die Möglichkeiten eines intelligenten Hauses anhand von mehreren Geschichten – sogenannte User Stories – präsentiert, die typische Alltagssituationen repräsentieren. In weiterer Folge werden Anwendungen aus diesen User Stories, als auch andere interessante Anwendungen, klassifiziert und in die verschiedenen Bereiche der Haustechnik unterteilt. Neben einer detaillierten textuellen Ablaufbeschreibung erhalten die wichtigeren Anwendungsfälle ebenfalls eine graphische Repräsentation – sowohl als UML Anwendungsfall- als auch Aktivitätsdiagramm. Vor allem die Aktivitätsdiagramme stellen eine solide Basis dar um die Komplexität, die die künstliche Intelligenz eines *Smart Homes* besitzen muss, abzuschätzen. Die Anwendungsfalldiagramme dienen eher als Übersicht über die auszuführenden Aktionen. Schlussendlich wird noch anhand einiger Beispiele ein kurzer Blick auf die tatsächlich mögliche Reduktion des Energieverbrauchs geworfen.

Abstract

This work's research subject covers the possible applications of building automation in private households, also known as *Smart Home*. This sector is already of common use in office buildings. Now, the continuously increasing energy consumption of the residential area makes this market more and more attractive to private utilization. A careful evaluation of the applicability as well as the serviceability needs to be elaborated. Especially the enhanced possibilities in this sector that can be provided by a potent artificial intelligence will be examined.

In the first instance, the term *smart home* will be specified more clearly and the criteria, which need to be fulfilled by such a building. A rough overview of available control networks is followed by a description of current problems and challenges preventing the technology's big breakthrough at present. The main part of this thesis presents the possibilities of an intelligent house. For this purpose user stories are presented that show typical situations in everyday life. As consequence these user stories' use cases and other ones will be classified in the various areas of home automation. Next to a detailed textual description of the operational sequence, selected cases receive a graphical representation – both as UML use case and activity diagram. Especially the activity diagrams provide a solid basis for the evaluation of the complexity of an artificial intelligence inside a smart home. The use case diagrams rather serve as schemes for the actions that need to be executed. A brief look on the actually possible reduction in energy effort concludes the work.

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1 Foreword

Goals

The goals of the diploma thesis are at first identification of established and possible future use cases of intelligent control in the sector of (smart) homes and buildings. After an introduction in this area and identification of current challenges the main goal of the thesis is presented. The use cases are selected from several areas of home automation like heating, ventilation and air-conditioning (e.g. automatically controlled windows linked with CO_2-sensors in meeting rooms), security, lighting, brown or white ware and more. Especially the increasing significance of artificial intelligence will be thoroughly examined for the increase in effectiveness and comfort. The use cases will be described, classified and evaluated according to their benefits for the users' lives and their possible ecological effects.

Results

A contribution of this diploma thesis will be a description, graphical representation and classification of use cases in smart homes and functional buildings. Many of these use cases have a lot of potential to be enhanced and be supplemented further with new features. They are a valuable foundation and a first step in a further design, as well as implementation and testing process of a smart home. After perusing this thesis the reader has an insight in the smart home area and gets a glimpse at the possible enhancements that can be achieved by using artificial intelligence.

Methodology and Steps

The diploma thesis will contain a brief introduction in the area of home automation with its history, diffusion in the market and an outlook in the near future and its acceptance in the real world. The first steps were an intense literature study in the building automation area. Ideas and stimuli were taken from already existing products, projects and concepts and this collection was separated into single use cases and classified into different sectors of building automation like HVAC or lighting. To present the possibilities in a common context, user stories were designed that handle situations in single and multi person households in an informal way. The use cases were developed further and received a detailed textual description. Some of them were also represented as UML use case and activity diagrams as well.

1.1 Glossary

Artificial Intelligence – is the intelligence of machines, "the study and design of intelligent agents"[1]

Ambient intelligence – see: pervasive computing

Brown ware device – another name for consumer electronic devices

CPU - Central Processing Unit

DLNA – Digital Living Network Alliance

e-Home – see: smart home

EchoNet – Energy Conservation and Home Network

HES – Home Electronic System-Architecture

HGI – Home Gateway Initiative

HVAC – Heating, Ventilation and Air conditioning

IGRS – Intelligent Grouping and Ressource Sharing

Intelligent Home – see: smart home

KNX - Konnex

LON – Local Operating Network

OASIS - The Organization for the Advancement of Structured Information Standards

oBIX - OASIS Open Building Information eXchange Technical Committee (oBIX)

OSI – Open Systems Interconnection

Pervasive computing – an overarching networking of everyday objects and life with intelligent objects

Powerline – electric wiring is used as transmission medium for networks

Smart Home – a house equipped with an artificial intelligence to control sensors and actuators, to fulfill the inhabitant's needs

Ubiquitous computing – Is a concept where the computers are integrated in everyday objects, see: pervasive computing

White ware device – electrical household devices used for cooking, washing, cleaning or body hygiene

RPC – Remote Procedure Call, technique to call functions on a computer in another address space

SOAP – Simple Object Access Protocol, network protocol to exchange data between different systems

REST – Representational State Transfer, software architecture style for distributed systems

[1] Poole, David; Mackworth, Alan; Goebel, Randy, "*Computational Intelligence: A Logical Approach*", New York: Oxford University Press, 1998

2 Home Automation and Smart Homes

The first chapter of this thesis concentrates on home automation in the non-business area. It begins with a short history of technization of homes and buildings beginning in the 1920ies and going up until the turn of the millennium. After that, a discussion is following that aims to define which characteristics a smart home should have. Hereupon, a selection on different control networks that currently coexist in the home automation sector is presented. These are described and their advantages and disadvantages are identified. The next part states some current problems and challenges that need to be addressed before smart homes can have a breakthrough in the consumer market. Finally, several interesting projects in that area as well as demonstrators managed by different universities and research initiatives are presented.

2.1 Introduction and History of Smart Homes

The area of Building automation in a non-business area is known by many terms. Some call this area „Home Automation“ or the houses „Smart Home“, „Intelligent Home“, „e-Home“ and many more. Though not all of them describe the same aspects and slightly differ in their definition, they express how a modern home can be equipped with up to date technology to support its inhabitants, increase their comfort and reduce energy consumption.

With electricity becoming available to a broader number of people until 1920 the first electronic devices like vacuum cleaner, food processors and sewing machines appeared in households and started the automation of homes. The next big breakthrough occurred after the Second World War – in 1940 already 65% of UK's households were powered with electricity [HARP2003] – as white ware devices (refrigerator, electric cookers and washing machines) started penetrating the domestic market and in the 1950ies televisions became available already. In the 1960ies and 1970ies more electronic appliances – such as toasters, coffee makers, electric irons … – emerged and technologies like thermostats in combination with a central heating became standard in new built structures. In the 1980ies – next to color television and also video recorders – microwave ovens, tumble dryers or freezers were becoming popular and appeared in private households. Cordless and mobile telephones were introduced and accepted by the first people. Since then many entertainment devices started to arise like VD players, gaming consoles, TVs with set top boxes and with the end of the decade also the first personal computers could be found in various homes. Above all, the broad acceptance of PCs made a significant change, by obligating differences between work place and home. Tele-working was becoming practicable and popular. The saturation of PCs in Austrian households rose from 49.2% in 2002 up to 74.9% in 2009[2]. Also 98.7% of Austrian companies were using computers back in 2009 already. Finally, with the Internet becoming affordable to more and more people – at beginning of 2008 51 % of European people were using the Internet – a mass of new services appeared (online banking, shopping …) and more to come like Video on Demand, Voice over IP and so on. In Austria, the number of households using Internet increased from 33.5% in 2002 to 69.8% in 2009 and even 57.8% were using broadband internet access. With further acceptance and prevalence of computers and web accesses this can be a critical point in the breakthrough of automation and artificial intelligence in households. Meanwhile products called "Home Servers" are available to store personal data like music, photos and videos as well as documents. With such "Home Servers" and attached network devices becoming available in more homes, a next step to an automated house, with a computer that controls and manages lighting, HVAC and more, will not be that big for people.

With the increasing amount of electrical devices that households are equipped with of course also the energy consumption increased significantly. The energy share of the residential area developed steadily while industry and the commercial sector reduced their energy consumption in the last years. Although

[2] Statistik Austria, "Verbindungstechniken für den Internetzugang in Haushalten 2010", URL: http://www.statistik.at/web_de/statistiken/informationsgesellschaft/ikt-einsatz_in_haushalten/022207.html, last accessed: 2010-07-15 16:30

many manufacturers are lowering the amount of power needed by their devices – especially in the last decade a lot of improvement was made – the energy share does not appear to drop due to the fact that the appliance number is rising undaunted. Nowadays, a lot of household are equipped with a lavatory machine, a tumble dryer, larger TV screens are appearing and also air condition is found in a lot of houses.

2.2 Smart homes

The term "*smart home*" is rather new. Having the first wired homes in the early sixties of the 20th century, usually built by hobbyists, the first mentioning of the expression "*smart home*" was in the year 1984 by the American Association of House Builders. Their areas of interest were primarily building, electronics, architecture as well as telecommunications and energy conservation. Unfortunately these initial intentions on what a smart home should be capable of do not fulfill the requirements of this thesis.

To specify the term "*smart home*" more precisely a home is not smart because it uses modern technologies and is environmentally friendly. Using photovoltaic power producers, recycling water and requiring less energy than a normal house, does not make a house smart automatically – though many technologies like these are used in smart homes. The key feature is mentioned by the term smart – meaning that the house has to think and makes decisions on its own, without requiring any stimuli of its inhabitants. In other words: The smart home has to be equipped with an artificial intelligence.

Frances K. Aldrich [HARP2003] stated five classes of smart homes:

1. Homes which contain intelligent objects: A home fulfilling this class has several standalone appliances and objects that are equipped and react with some sort of intelligence.
2. Homes which contain intelligent, communicating objects: In order to add and improve functionality the appliances can exchange information between one another.
3. Connected homes: The home is equipped with a network allowing interactive and remote control of systems. Also services and information can be accessed from within and outside the house.
4. Learning homes: Activities and patterns in the home are recorded and stored to anticipate the needs of the user and also control the technology accordingly.
5. Attentive homes: The home is aware of activities and locations of the users as well as the objects. With this information the house reacts to and predicts the user's needs and controls the technology accordingly.

This thesis presupposes that a smart home fulfills at least class four of the above hierarchy to successfully implement the uses cases mentioned later. Some of them even require class five to be reasonable.

As the technology to build a smart home has already been existing for a couple of decades a few questions arise. Two of them may be "What prevents the smart home from being popular in the consumer market and why has the breakthrough not happened until now?" Up to now only a few "really" smart homes are built and sold on the commercial market. Most of them are either showcases of manufacturers, universitary research labs or labs of other research facilities like the Frauenhofer Institut. [GANN1999] identified several causes why smart homes have not had their breakthrough up to now:

- There is a lot of initial investment needed, restricting the target group to the middle and upper levels of income.
- Potential buyers must first be convinced from the benefits.
- The house stock in Europe is rather old. Manufacturers have to find a way to "retrofit" existing houses.
- The market lacked of a common protocol that the smart homes industry tended to on/off switching of single appliances, which does not require any network installation.

- Suppliers have adopted a narrow "technology push" approach and paid too little attention to understanding the user's needs. Consumers want systems which will help them with managing everyday tasks, offer labor saving and task simplification, ease of operation, remote control and cost reduction [MEYE1996]. There is a gap between consumer requirements and the products that are available. Meyer and Schulze suggested winning the acceptance of women, because they are still responsible for a major part of domestic work.
- Suppliers have done very little to evaluate the usability of their products. It is not a simple task however because of the diversity of the population, variation of the context of use or that sometimes a prior training is necessary.

According to the problems that exist which prevent the smart home's breakthrough Frances Aldrich also posted a set of solutions [HARP2003]:

- The industry must develop solutions which address real users' needs.
- Solutions must operate at 3 levels (generic technologies, providing basic compatible "building blocks" for context-specific systems (adoptable to a wide variety of dwellings), personalized systems (tailored to specific users and households).
- Solutions must offer functionality, ease of use, affordability, reliability, upgradability, replicabilitly, ease of installation.

Inspired by the problems and solutions stated by [GANN1998], another chapter of this thesis investigates further problems and concerns of the end-user market and tries to answer or dissipate fears and concerns.

2.3 Control Networks of Home automation

As the last chapter took a closer look on the history of smart homes and defines which abilities a smart home should have, this chapter examines the current basis available for such a house – the control networks. A short overview on current standards and initiatives of different control networks in home automation is presented. The listing does not make a claim of completeness due to the massive amount of technologies that co-exist in this sector. Also the different control networks and protocols span a different number of layers in the Open Systems Interconnection (OSI) Reference Model which makes them quite difficult to compare. Nonetheless, this should give an idea about the opportunities and problems that exist in the current standards and protocols of home automation and smart homes.

2.3.1 KNX

One of the most widespread systems is the KNX standard. The goal was to develop a standard for the building automation market that ensures interoperability and compatibility for different systems or devices from different manufacturers.

The history of KNX goes way back to the year 1990 when leading developers and manufacturers united in the "European Installation Bus Association" (EIBA), which was later on renamed to *Konnex-Association* (KNX association). Today, the KNXA consists of over 170 members [KNX1] and 58 scientific partners [KNX2] from all over the world. The former standards *European Installation Bus* (EIB), *European Home Systems Protocol* (EHS) and *BatiBus* were merged into the new standard, simply called KNX. The first release was 2002 and it was accepted as international norm (ISO/IEC 14543-3) in November 2006. The KNX standard is downwards compatible which means, that all products certified as EIB products are compatible with the new standard. In September 2009 the new KNX 2.0 standard was published [KNX3] with many improvements and additions to the previous version including a new generation of KNX-RF or an enhanced KNX Easy Installation Mode. Especially KNX newcomers should be helped in development with the new release.

The KNX standard supports a broad range of applications reaching from control of HVAC or white ware devices, lighting and shading up to security issues. There are three basic configuration modes specified, A-, E and S-Mode.

- A-mode (automatic mode) devices configure themselves automatically and with the end user as target group.
- E-mode (easy mode) devices require basic skills in configuration and installation.
- S-mode (system mode) devices are installed into especially tailored building automation systems which need to be configured and programmed by specialists.

With the increasing diffusion of networks based on the Internet Protocol (IP) the KNXnet/IP was developed as an extension to existing transmission media. With KNXnet/IP remote configuration and control is possible within a subnet or across several subnets.

Profile	KNX
Standard	• ISO/IEC 14543-3 since 2006
Status	• KNX 2.0 released in November 2009
Operational area	• Lighting and shading • HVAC • White ware appliances • Security sensors • Audio control • …
Transmission medium	Wired • Twisted Pair (TP1) • Ethernet (KNXnet/IP) • Powerline Wireless • KNX-RF
Pros	• Well established • Broad operational area • Wide range of transmission media • Open standard • No new wiring necessary (in case of Powerline or KNX-RF) • Can be implemented on any microprocessor platform
Cons	• Connection quality depends on transmission medium (e.g. Powerline) • Insecure (no encryption specified)

2.3.2 LON

Exactly as KNX, *LONWORKS* was developed in the early 90's of the last century. Echelon Corporation, the inventor of *LON* (Local Operating Network), wanted to create an outright platform for building automation networks, which consists of intelligent devices, called nodes, which communicate over different communication media with a common communication protocol. For further development, Echelon and some other enterprises founded *LonMark International* [LON1] with more than 400 members worldwide [LON2]. In December 2008, LON technology was becoming a part of the ISO family in the 14908-x series.

Figure 1: LonMark Logo

The *LonTalk* protocol defines layers 2 to 7 of the OSI Reference Model. The physical layer is filled by several wired or wireless technologies. The core element of *LonWorks* is the Neuron chip which can be found in nearly all *LON*-products. The neuron chip consists of the Media Access

CPU, which is responsible for the physical connection to the network, the Network CPU, responsible for coding and decoding of the network messages and finally the application CPU, implementing the automated functionality. In 1999, the protocol was opened to general purpose processors.

Profile	LON
Standard	• ISO 14908-x since December 2008,
Status	• LonWorks 2.0 (April 2010), Documents currently undergoing publication (2010-04)
Operational area	Domestic sector: • HVAC • Lighting and shading • Security Sensors • … Other: • Street lighting • Transportation (e.g. Trains) • Utility • Industrial automation • …
Transmission medium	Wired • Twisted Pair (TP1) • Powerline • Fiber optics • EIA-485 • Coaxial-cable Wireless • Radio (since LonWorks 2.0) • Infrared (since LonWorks 2.0)
Pros?	• Well established • Broad operational area • Wide range of transmission media • No new wiring necessary
Cons?	• Insecure (48 bit encryption) (LON 1.0)

2.3.3 Digital Living Network Alliance

The goal of the *Digital Living Network Alliance* (DLNA) is to provide a platform for sharing, presentation (streaming) and transformation of audio and video media on different devices like PCs, TVs, mobile phones or networking devices. The main feature should be an easy way to stream videos from e.g. a "*Network Attached Storage*" (NAS) to a TV also for non-professionals in computers and networks. Especially the High Definition video area is targeted.

On the contrary to the other organizations, the DLNA's focus lies on consumer electronics. It was founded in the year 2003 *as Digital Home Working Group* (DHWG) by Sony and Intel. In 2004 the name *Digital Living Network Alliance* ensued. Today, there are more than 250 members having their focus in entertainment electronics, mobile, communication or other sub branches of information technology like Cisco, Nokia or Samsung. The current version 1.5 was released in 2006.

Figure 2: DLNA certified logo

There are three different device classes and several subclasses, as there are Home Network Devices (e.g. TV, MP3-player, network drives, cameras or printer), Mobile Handheld Devices (mobile phones and all devices that fulfill the home network devices category but are mobile) and the Home Infrastructure

Devices, which are responsible for transforming the media for the different devices and serving as a bridge between them.

All compliant devices (e.g. Sony Playstation 3, HP MediaSmart TV or Nokia N95 mobile phone) are certified by the DLNA Alliance with a logo, indicating the consumer that this device features all DLNA requirements.

Profile	DLNA
Standard	• No ISO or national standardization
Status	• Version 1.5 from October 2006
Operational area	• Audio /Video (HD) streaming • Audio /Video (HD) sharing • Picture Sharing and printing
Transmission medium	Wired • Ethernet • Coaxial cable Wireless • Bluetooth • WLAN (802.11/a/b/g)
Pros	• Easy installation (UPnP) • High Data Rate • A lot of availably products
Cons	• Many common file formats just optional • In practical use still a lot of problems in interoperability

2.3.4 Intelligent Grouping and Resource Sharing

The *Intelligent Grouping and Resource Sharing (IGRS) Working Group* [IGRS1] released its first version of the IGRS protocol in July 2003. The main goal is to provide a common basis for sharing audio or video streams between different devices – like PCs, TVs or HiFi-Stations – in an easy way. The aspired target areas are private households, offices and also public areas. The working group was founded by Chinese enterprises like Lenovo, Konka or Hisense. In 2005 the IGRS protocol became Chinese national standard. Today, also enterprises like Phillips or LG Electronics are members of the working group.

In 2010, the IGRS became part of the ISO 14543-5 family which is also known as Home Electronic System-Architecture (HES).

Profile	IGRS
Standard	• Chinese national industry standard since 2005 • ISO 14543-5-1 (part of Home Electronic System Architecture) since 2010
Operational area	• Audio/Video streaming • Audio/Video sharing
Transmission medium	Wired • Powerline • Twisted Pair (TP1) • Ethernet Wireless • WLAN (802.11) • Bluetooth • UltraWideBand (e.g. Wireless USB, 802.15.4a)
Pros	• Open standard • More file formats supported than DLNA
Cons	-

2.3.5 Home Gateway Initiative

The *Home Gateway Initiative* (HGI) defines a home gateway in the following way: "*A home gateway is a device that provides broadband connectivity to the home and delivers services to, and from, an even-increasing number of end-devices in the customer environment.*" The scope includes broadband connection, communication, mobile integration scenarios (phone to network), guest and hotspot access, home office (use work office devices and services at home), entertainment (IPTV and radio, media server…), audio and gaming, remote access as well as management and security. The main goal is to deliver services (e.g. Video on Demand) in an easy and safe way from the provider to the consumer.

The HGI is an association of several small and big players in home gateway, networking and communication industry like Deutsche Telekom, France Telekom or Alcatel-Lucent. The purpose is not to establish a new standardization body in longer terms, but to agree on a set of functional requirements for home gateways. The first release was published 2006 specifying basic building blocks and requirements for the home gateway. The second release was presented in 2008 adding new features for better support of end-devices, networks and services. The third release is currently under development.

Profile	HGI
Standard	• No standardization pursued
Status	• Release 2 • Release 3 available as draft version
Operational area	• Home office • (Broadband) Communication and services • (Multimedia) Data sharing • Security • Management
Transmission medium	Wired • Ethernet • Powerline • Twisted Pair (TP1) • USB • Telephone line (RJ11 or RJ45) Wireless • WLAN (IEEE 802.11b/g, 802.11a/n not mandatory) • GPRS and UMTS • Bluetooth • …
Pros	• High security and encryption pursued
Cons	• Just a set of requirements, therefore no disadvantages known

2.3.6 Energy Conservation and Home Network

The Energy Conservation and Home Network (ECHONET) is a Japanese standard under development since 1997 by the *ECHONET Consortium* [ECHO1] which accomplished commercial phase in 2003. The primary scope lies in the domestic area and senior citizen homes, but also small office buildings and stores are lying within. One of ECHONET's main goals is to be keep costs of implementation low. This is fulfilled by using established transmission media such as Powerline, infrared or LonTalk. ECHONET covers nearly all areas of smart homes like HVAC, white ware devices, shading and home entertainment.

The architecture is roughly separated into three layers. The lower layer communication software, which is already provided by various transmission standards, the communication middleware, which handles the communication (data exchange, remote controlling) between different nodes. Another part of this layer is the abstraction of protocol differences, which is crucial for converting all networking protocols to ECHONET to provide a homogenous network.

ECHONET and its HK commands (House Keeping commands) cover all areas of building automation. There are predefined object groups that are called sensor related, air condition related, cooking-housework related (e.g. fridge, cook tops and small devices like coffee makers), health related, for management and control or housing/facility related (e.g. shutters).

Profile	ECHONET
Standard	• No standardization until now
Status	• ECHONET Specification Version 3.2
Operational area	• HVAC • White ware • Management and control • Sensors • Shading • Home entertainment (e.g. remote controls)
Transmission medium	Wired • Powerline • Twisted Pair • Ethernet • LonTalk Wireless • Infrared • Bluetooth • Low Power RF • WLAN (802.11a/b/g) • LonTalk
Pros	• Wide range of transmission media • Support for other protocols (e.g. LonTalk) • Plug and play functionality
Cons	• Only pursued in Japan • No open standard

2.3.7 CECED Home Appliances Interoperating Network

CECED (Conseil Européen de la Construction d'appareils Domestiques) [CECED1] Home Appliances Interoperating Network (CHAIN) was developed by the European association of household appliance manufacturers. Its main operational area covers all kinds of white ware devices, i.e. ovens and cook tops, fridges and freezers, washing machines and dryers, microwave ovens and even moveable air conditioner. CECEDs members include e.g. BSH Bosch, Siemens Hausgeräte, Electrolux, Miele and about 200 more. CHAIN is an abstraction of KNX and EHS (protocol and hardware) for manufacturer-neutral data exchange and controlling of household appliances. Communication media are either electric cables (Powerline) or the KNX radio standard KNX-RF. Therefore, no new wiring is necessary. Also, the devices are plug-and-play-capable so there need not be any special knowledge necessary for their configuration.

Products get a CHAIN certificate which guarantees full implementation of the standard and interoperability with other certified devices. Appliances supporting CHAIN allow the remote control and fault diagnosis, automatic maintenance, energy as well as load management of these devices. Downloading and updating of programs, firmware and service is also possible.

Profile	CHAIN
Standardization	• Industry standard • No international standardization
Operational area	• Mainly white ware appliances
Transmission medium	Wired • Powerline Wireless • KNX-RF
Pros	• Plug and play • Energy (saving) management • Same advantages as KNX
Cons	• Same disadvantages as KNX

2.3.8 OpenTherm

The OpenTherm association [OPENT1] was founded to get a simple system for the data exchange between boiler (slave) and "room control" (master). The goals of this association were to provide an easy way to install and start up advanced HVAC management similar to the conventional ON/OFF controllers. Further it should reuse the existing wires and need not use batteries. The OpenTherm Association consists of over 40 members including worldwide enterprises like Siemens or Honeywell. The actual version 3.0 was released in June 2008.

The association developed two versions of this standard. OpenTherm/plus or OT/+ is the full implementation of the standard, whereas OpenTherm/light or OT/- just represents a subset of the protocol's features which is easier to implement. The standard is in an ongoing development. Since its first publication with its primary focus on heating many new features joined the catalogue, like setting and reading the temperature of tap water, switching tap water on or off, reading the outdoor temperature, reading malfunctions and special controls due to the actual weather condition.

The new OpenTherm 3.0 specification introduced a new feature called Smart Power. This allows the master to request a slave into a low power mode – which is identically with the previous specifications – but also a medium and high power mode. The new power modes allow manufacturers to add new features to their products like touch-panels or additional sensors which could not be supplied completely with the low power mode previously. Also a multi point-to-point connection is defined now, which allows a single slave device to be managed by multiple master devices. The next release of OpenTherm should also define connections to various home bus systems and protocols (ZigBee, Z-Wave …) and also a plug & play functionality is worked on.

Profile	OpenTherm
Standardization	• No national or international standardization • De facto industrial standard
Status	• Version 3.0 (June 16th 2008)
Operational area	• HVAC (Heating control + sensors, …)
Transmission medium	Wired • 2 wire low voltage Wireless • KNX RF
Pros	• Using existing wiring
Cons	• Until now no interface defined to other protocols like KNX, LON, …

2.3.9 Meter-Bus (M-Bus)

The Meter-Bus (M-Bus) was originally described in the European norm EN 1434 – Heat meters but now it is a standard on its own. Since the year 2002 it is specified in DIN EN 13757-x. As the name might suggests the Metering-Bus is used for remote reading and networking of electricity, water or gas meters, but also supports all kinds of actuators and sensors to be connected with it.

The communication between a master device and a slave device (e.g. gas meter or even a PC) is established with a standard two wire connection which allows keeping the costs low. There is also no certain wiring specified, therefore a standard telephone cable (JYStY) may be used as well as twisted pair cable or Powerline. Even some end devices can be powered by the bus system itself without another source of energy. The M-bus supports up to 250 end devices including a master device. The data from the slaves (end devices) is collected and transmitted to the master device which can be a handheld device for instance or also a modem to send the data to e.g. the local energy provider.

Profile	M-Bus
Standardization	• DIN EN 13757-2 (physical and link layer) • DIN EN 13757-3 (application layer) • DIN EN 13757-4 (radio variant of M-Bus specified)
Status	
Operational area	• Remote metering of water, gas and electricity consumption
Transmission medium	Wired • 2 wire low voltage Wireless • Radio
Pros	• Easy to install • End devices can be powered by the bus itself • Wide range of transmission media • Long range networks with the help of repeaters
Cons	• 250 possible end devices can be too less for big building structures • No standardized plug connectors

2.3.10 ZigBee and IEEE 802.15.4

ZigBee is a radio transmission standard propagated by the *ZigBee Alliance* [ZIGB1] that specifies the upper layers of the ISO/OSI layer architecture and uses IEEE 802.15.4 as a base for the lower layers (PHY and MAC). The intentions for ZigBee's development were embedded applications that require low data rate and low power consumption. Also maintenance-free radio switches and sensors with a limited battery supply in hard-to-reach areas are targeted. Up to now, ZigBee has evolved to other areas in smart homes like home entertainment or remote controlling.

The first revision of ZigBee was released in 2004 and had two successors until now, which were released in 2006 and 2007. ZigBee2006 and ZigBee2007 are not backwards compatible with the first release. An alliance of enterprises like Samsung, Phillips or Motorola called ZigBee Alliance developed this industry standard and over 230 companies are members of this alliance today. The first certified products were released in 2005.

Three device types are specified in ZigBee:

- **ZigBee End Devices** are simple devices (e.g. lighting switch), that have only a part of the protocol stack implemented. In IEEE-terminology they are also called RFD (reduced function device) and build a star-topology with their router, where they are registered. ZigBee End Devices can be battery powered and also have a sleep mode installed for energy saving purposes.

- **ZigBee Routers** – or FFD (Full Function Devices) in IEEE terminology – have implemented the whole protocol stack. They are building a tree- or mesh-topology with other routers. These devices must not be powered by batteries and cannot enter a sleep mode.
- One Router is the **ZigBee Coordinator** who is responsible for administration of the network. The Coordinator is the root node of the ZigBee network and can be linked to the root of another network tree.

Profile	ZigBee
Standard	• IEEE 802.15.4 standard • ZigBee itself is not internationally standardized
Operational area	• Sensors and monitoring • HVAC • Lighting • Radio switches and sensors in hard-to-reach areas • Home Entertainment (3D shutter goggles or short range devices) • Industry and medicine technique
Transmission medium	• Wireless IEEE 802.15.4 @2,45 GHz and @868 MHz
Pros	• Security (AES 128bit possible) • Long range (960m with 32 node hops) • 2^{64} nodes possible (more than 18 quintillion) • Choice of frequencies
Cons	• Coordinator is single point of failure (sPoF) • Interferences with Bluetooth and WLAN in same area on higher frequency band (2,45 GHz) reported [KART2006] • Low transmission rate for home entertainment applications

2.3.11 Z-Wave

Z-Wave is a wireless communication protocol developed by the enterprise Zensys and later by the *Z-Wave Alliance* [ZWAVE1]. It is a direct competitor to ZigBee, rivaling with the same operational area. Until now, there are more than 170 members in the Z-Wave Alliance. The intention for inventing this protocol was to fill the market for domestic light and alarm systems.

In Europe Z-Wave sends on 868.42 MHz ISM band and the transmission rate spans from 9.6 kBit/s up 40 kBit/s. The Z-Wave network is a meshed network with one or two master controllers, who are responsible for routing the packages. The Z-Wave nodes also include the function as a repeater. If two nodes are too far away to communicate directly, the data can be sent over a node that is in between.

The latest developments tend to support also wired communication (Powerline).

Profile	Z-Wave
Standard	No standardization
Operational area	Sensors and monitoring, HVAC, Lighting, Radio switches and sensors in hard-to-reach areas, home entertainment (remote controls)
Transmission medium	• Wireless (868. 42 MHz) up to 30 meters • Wired (Powerline)
Pros	• Does not interfere with WLAN or Bluetooth • Long range (up to 120m with four node hops) [STEE2009] • 128 bit encryption (BFSK modulation)
Cons	• Low transmission rate (9.6 or 40 Kbit/sec)

	• Proprietary • Controller can be functionally destroyed by a controlled node becoming damaged [STEE2009] • More expensive than ZigBee • Smaller WPANs than ZigBee

2.4 Current Challenges

This chapter focuses on current challenges in home (and partly also building) automation and hurdles to overcome before bringing smart homes to a broad consumer market. In Chapter 2.2 a few existing problems were already mentioned. The selected challenges are quite important ones that need to be addressed. Of course there are also other issues that need attention like maintainability, manageability or reliability. Because this chapter just wants to give an insight in current problems not all are dealt with here.

2.4.1 Interoperability (Integration and Standards)

"Interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged."[3]

A current problem of home and building automation is the large amount of different control networks like it can be seen in the previous chapter where just a selection of the most popular ones is presented. Although many producers formed alliances and founded standardization initiatives there is still a lot of work to do, to ensure full interoperability and integration. The massive amount of different standards makes it nearly impossible for most consumers to choose suitable products that should interact in their homes. As this is already a huge problem in the multimedia sector (different audio/video formats, not all players can work with every format …) it becomes even worse when sensor networks, white ware appliances, HVAC devices, etc. should work together and exchange and process their data properly.

In the last years many systems assure to function with other systems by an appropriate middleware solution. A project that a lesson can be learned from is ECHONET which can be used with LonTalk devices which was already mentioned in chapter 2.3.6. A first step ensuring interoperability in the building automation sector was made with *OASIS Open Building Information eXchange Technical Committee* (oBIX). The *Organization for the Advancement of Structured Information Standards* (OASIS) is a technical committee, which "drives development, convergence and adoption of e-business standards" [OBIX1] and was already founded in the year 1993. The thought behind oBIX is "to define a standard web services protocol to enable communications between building mechanical and electrical systems, and enterprise applications" [oBIX1]. Nowadays, most electrical devices are equipped with embedded digital controls. Mostly they are cheap and not enabled for TCP/IP. The more expensive devices though can communicate or be controlled over TCP/IP but are bound to specific protocols like KNX, LonTalk or any other network protocol. The advantage of web services is that they are designed by definition for World Wide Web/Internet and therefore also the TCP/IP protocol whereas most of the other control networks were just adapted to the Internet protocol. Up to now, oBIX is focused on enterprise building automation, but surely can be enhanced to provide the residential sector with additional commands like the support of brown and white ware devices.

There are already a lot of positive experiences in computer science regarding web services. They are used in the aspect of *Remote Procedure Calls* (RPC), *Simple Object Access Protocol* (SOAP) or *Representational State Transfer* (REST) just to name a view of their well known applications. Besides, they also provide a lot of advantages like the usage of open standards which are license free or independence of the underlying

[3] "Interoperability", Institute of Electrical and Electronics Engineers, IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries, New York, NY, 1990.

transmission protocol. As the performance and reaction time is playing a minor role in most building automation use cases, the problem of web services [GOVIN2000] that was just mentioned can be ignored in most usage scenarios. As a simple example it is not crucial if the heating is turned on in a room as soon as the temperature drops below 20° Celsius. The inhabitant does not recognize the fact that it is turned on a few seconds after that. A lot of other examples regarding the low impact of performance can be mentioned. Of course the different approaches in security should be worked on as the W3C's WS-Security standard is not mandatory.

For this reasons and coupled with a strong security standard, web services techniques are a good choice in establishing interoperability in smart homes. The most important method to provide this are the standardized interfaces and commandos so a potential buyer can feel certain that all functions will perform as requested.

2.4.2 Sustainability

"Sustainability is the capacity to endure. In ecology the word describes how biological systems remain diverse and productive over time. For humans it is the potential for long-term maintenance of well being, which in turn depends on the maintenance of the natural world and natural resources."[4]

Sustainability in the context of smart home has two meanings. Like indicated in the definition above, the smart home needs low natural resources in its production and the more important one, consumes low natural resources (electricity, water, gas) in its usage duration. Nearly 80 percent of a house's expenditure of energy is consumed during its operation. A big share in a household's energy effort is wasted by, for example, having rooms lighted up when nobody is in it, electronic appliances that are still active although nobody uses them and so on. Also dripping faucets are a throw away that can be a major concern in dry regions of Earth. These are just some simple examples that will get a closer look in the main chapter of this thesis. With AI built into the house supporting its inhabitants in their routines and daily living such squander can be reduced to minimum.

In the last years, it has become pretty usual that new buildings are equipped with their own power producers. Active and passive solar systems, photovoltaic systems or windmills are connected to the house's power net providing it with renewable energy. Some electric companies even support the feed in from these producers in the company's power net. A lot of energy producers are just used for the warming of water (e.g. in pools) or other simple tasks but waste a lot of their potential. A smart home can enhance their efficiency and effectiveness and significantly reduce the energy expenditures. For example, usage times of energy intense appliances and tasks can be shifted to times, when the house's power producers are most efficient providing a big share of the energy that is used. Another possibility would be to pan solar panels according to the position of the sun for maximum energy yield and a lot more.

The second meaning of sustainability is on the technical side. Due to the short history of home and building automation − especially in the residential area − (compared to the history of building trade) new technologies and standards arise and are evolving rapidly. Software can easily be updated to a newer version (if it is backwards compatible) but unfortunately hardware is not as pleasing. It has to be ensured that e.g. wiring, sensors and actuators that are included in the building stock are still functional and compatible in at least 15 years and preferable over the whole building lifecycle which spans normally from around 75 up to 100 years. Some other hardware parts like the home server or displays though can rather easily be updated or replaced with more actual versions.

[4] Bromley, D., "sustainability", the new Palgrave Dictionary of Economics, 2nd Edition, 2008

2.4.3 Privacy & Security

"Right of a person to be free from intrusion into matters of a personal nature. […] privacy is a right not to have one's intimate life and affairs exposed to public view or otherwise invaded."[5]

"[..] Information security means protecting information and information systems from unauthorized access, use, disclosure, disruption, modification, perusal, inspection, recording or destruction"[6].

With the smart home knowing about every movement and activity of its inhabitants a lot of question arise concerning privacy. The smart home tracks the people inside, monitors them in every room and stores a lot of personal data. Therefore, one of the most important topics and people's reservations about is keeping this data secure. The following part of this thesis discusses some features that are incorporated in smart homes that need to be addressed to obtain the consumer's confidence.

Because the smart home is equipped with various video cameras to track the user's position, path and activities (the reason for this will be described in a later chapter), this will very likely be the most problematic topic that people will think about before giving this technology a chance. Being watched the whole day and monitored in your own privacy sphere is an unsettling thought. Although the data may not be stored by the smart home system itself because there is no need for later analysis, if somebody has access to the smart home's network, the intruder may also have access to the cameras and therefore the video material. A lot of other sensitive data may also be stored like personal documents, telephone calls, information about the daily routines and so on.

Another concern is the increased networking of household appliances and installations. Not all devices and sensors can be managed by a wired connection or it is simply impractical (confer operational area of ZigBee and Z-Wave). In future buildings – especially multistory houses or apartment buildings – when every flat is equipped with sensors and actuators controllable by radio transmission this could become a major issue. The fact that everybody is able to read for example the status of your HVAC or which and how much luminary is switched on is not a big concern. Far more disturbing is the possibility to manipulate the actuators or the data received by the system. Such an intruder in the system may just annoy the inhabitants by turning off various lights or heating up rooms to e.g. 30 degrees, but the interloper can also sabotage or even damage the house's equipment with such opportunities. Another problem is the interference with signals of the equipment of other flats which can lead to reliability issues. The actuators may even receive commands from another apartment unit or the overlapping signals disturb the receipt of correct data.

Having these issues and concerns revealed, the security of networks should not be kept unmentioned. Radio connections (WLAN, Bluetooth or other wireless sensor networks) are today of common usage in households and a smart home is surely equipped with such possibilities. WLAN networks provide already good security possibilities with encryptions like Advanced Encryption Standard (AES) but sensor networks still need improvements in this area as it was described in chapters 0 and 2.3.11. The usage of AES or even its predecessor the "Data Encryption Standard" (DES) will make a huge leap in wireless network security.

Another very important issue concerning privacy is caused by medical possibilities of the intelligent house like e-Health services. A smart home may be equipped with a personal health database and with possibilities to retrieve the inhabitant's body information like pulse rate, blood pressure or also medications that are currently taken. Also that data may be shared with the person's doctor(s) or health personnel. This

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[5] rights of privacy (2010), In *Encyclopædia Britannica*. Retrieved October 19th, 2010, from Encyclopædia Britannica Online: http://www.britannica.com/EBchecked/topic/477278/rights-of-**privacy**

[6] "Title 44 of the United States Code Paragraph 3542", also available on the Internet, URL: http://www.law.cornell.edu/uscode/44/3542.html

data needs to be secured from external access heavily. A lot of questions occur that also were of concern in the discussion about the Austrian "e-card"[7] or the German "*Gesundheitskarte*"[8].

2.4.4 Extensibility

"Ability of a software system […] to allow and accept significant extension of its capabilities, without major rewriting of code or changes in its basic architecture." [9]

An even more accurate definition is provided by Wikipedia:

"In software engineering, extensibility (sometimes confused with forward compatibility) is a system design principle where the implementation takes into consideration future growth. It is a systemic measure of the ability to extend a system […]. Extensions can be through the addition of new functionality or through modification of existing functionality."[10]

Another important factor to ensure breakthrough in the residential area and all levels of income is the extendibility of a smart home. This applies to the functionality of the artificial intelligence as well as the hardware parts like actuators and sensors. For example, the basic version of the smart home is fully equipped with wiring bust instead of putting sensors and actuators everywhere to fullfill its complete potential it is prepared with placeholders and the smart home's AI provides only elementary features like controlling the HVAC system or turning off all lights when the user is leaving the house. The inhabitant can buy or extend additional functions to control the luminary in more ways, adjust HVAC to different situations, retrieve and use forecasted weather data and much more. He[11] can expand the features bit by bit or just upgrade existing functions without bigger building operations. Another term describing this concept is modularization. Also this will help the users to slowly familiarize with an intelligent home and giving away the sole control of the house which makes future improvements in the smart home's functionality easier to adapt to.

Like already mentioned before, updating software – in particular the AI – is no obstacle to overcome. Like it is already common with every other piece of software the smart home's nervous system can be updated and extended in its functionality. So maybe a user can choose from a list of expansion modules which he would prefer and does not need to install functions that he does not like, allowing to keep the effort lower which improves the penetration of the market and be of interest for a bigger audience.

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[7] "e-card", from Wikipedia, available on the Internet, URL: http://de.wikipedia.org/wiki/E-card_%28Chipkarte%29, 2010-10-09

[8] "Elektronische Gesundheitskarte", from Wikipedia, available on the Internet, URL: http://de.wikipedia.org/wiki/Elektronische_Gesundheitskarte, 2010-10-10

[9] "Extensibility", from BusinessDictionary, available on the Internet, URL: http://www.businessdictionary.com/definition/extensibility.html, 2010-11-15

[10] „Extensibility", from Wikipedia, available on the Internet, URL: http://en.wikipedia.org/wiki/Extensibility, 2010-10-10

[11] In order to simplify things the male personal pronoun is used instead of user or inhabitant. Of course a user can be female or male.

2.4.5 Adaptability

Is the "Ability of an entity or organism to alter itself or its responses to the changed circumstances or environment. Adaptability shows the ability to learn from experience, and improves the fitness of the learner as a competitor."[12]

Another important topic to increase acceptance in population is the adaptability of a smart home – it can also be called customization. This can either be mapped to the software related design as well as the equipped hardware. The system's reaction has to adapt to the user's behavior and a lot of situations that occur in the house. This can be achieved by initially defining personal settings like optimal room temperature or air humidity, brightness level and condition in certain rooms. Also the inhabitant can decide the kind of the event reports from the system or how often he wants to receive them. But also simple tasks like setting the wake up time in a personal calendar can be specified. If the user likes to, the smart home can fine tune these settings by monitoring the user's behavior. For example if the user is raising the brightness level every time he occupies a room the system sets the initial level higher than the user has defined. Also the system may reduce heating in rooms that are only entered at certain times during a week – e.g. a hobby room. Many similar examples can be thought of where an intelligent home can react to the user's routines and habits. But the system settings and reactions to the user are not the only thing that can adapted to the wishes and needs. Also graphical interfaces on displays may be adapted to the user's likes. This includes the house's controlling "screens" and abilities that are presented as well as how information is displayed like newspapers on a tablet-PC or web sites on different devices with different screen sizes.

2.4.6 Pervasive Computing and Usability

"Refers to the use of computers in everyday life, including PDAs, smartphones and other mobile devices. It also refers to computers contained in commonplace objects such as cars and appliances and implies that people are unaware of their presence. One of the Holy Grails of this environment is that all these devices communicate with each other over wireless networks without any interaction required by the user."[13]

The term pervasive computing is often used synonymous with ambient intelligence or ubiquitous computing, although these words describe slightly different aspects of the same vision – to deviate from the so called desktop paradigm, which currently prevails. The idea, which is referenced by these words, is that computers are integrated in everyday objects and activities. A person that is using computers to obtain or manipulate information should not be aware of the fact that he uses a standalone computer like it is the fact when using a desktop PC or notebook these days. The technological advance is bringing a lot of devices that can already close up to the pervasive computing definition. There are already fridges available with connection to the Internet, digital picture frames are standing on shelves that can also display current weather data and so forth. In a smart home carry able displays and computers like tablet PCs and as an actual reference Apple's iPad[14] and of course also eBook readers like the Amazon Kindle[15] will be of common use. Also mobile phones are equipped with more and more features and functionality and the gap between them and special purpose devices like Kindle or iPad is closing. Also the pendant to stationary computers may be just small cubes that you can put in your pocket like you can do it with an mp3-player nowadays or a coffee table at the sofa with a touch screen as a table top like a prototype device from Microsoft suggests called "Surface"[16]. Smaller displays will be integrated in the walls in rooms and halls to

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12 "Adaptability", from BusinessDictionary, available on the Internet, URL: http://www.businessdictionary.com/definition/adaptability.html, 2010-11-10

13 "Pervasive Computing", from PC Mag, available on the Internet, URL: http://www.pcmag.com/encyclopedia_term/0,2542,t=pervasive+computing&i=49146,00.asp

14 "iPad product page", available on the Internet, URL: http://www.apple.com/ipad/, 2010-10-14

15 "Kindle product page", available on the Internet, URL: http://www.amazon.com/Kindle-Wireless-Reader-3G-Wifi-Graphite/dp/B002FQJT3Q, 2010-10-08

16 „Microsoft Surface Homepage", available on the Internet, URL: http://www.microsoft.com/surface/

control the different features of the smart home. They are also usable as a communication and quick Internet access platform and for the user they are available just a few steps away. A lot of other invisible and integrated computers will appear in a smart home giving the inhabitant information that he needs and supporting him in his activities.

But at the same time, computers are integrated in every object in a household the usability must not be neglected. The International Organization for Standardization defines usability as follows: “The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."[17]

All those devices, which are equipped with more and more technology, should not be computerized just for eye candy or having a huge feature list to boast with. Because something is possible it is not always reasonable to put it into practice. The additional functionality should always support the purpose or simplify the use of the object. Although this is quite an unrealistic example, a coffee maker with an integrated TV will never be a good alternative to a normal coffee maker. This is just raising the energy consumption and a normal display is always more comfortable to watch with than such a hybrid model.

[17] “ISO9241 – 11.3”. Definitions, International Organization for Standardization, 1998

2.5 A Selection of Projects in the Smart Home Area

This chapter shows a selection of current projects and model houses in the area of smart homes and home automation. The first two examples describe interesting projects concerning ideas on achieving energy reduction in households taking completely different approaches. After that, some initiatives and smart home laboratories are presented. The majority is situated in the German speaking world while the rest is situated in the United States. Some of the smart home projects where already built in the late nineties whereas others were just finished in the year 2009. First a short description and history of the project/initiative are given. Also the main research interests are mentioned and in which way projects are conducted. After that a list of research topics that are currently worked on are shown.

2.5.1 Visualization of Energy Consumption of Single Devices – ECOIS II

Osaka University conducted a project called ECOIS II [UENO2006] in the years 2002 and 2003, where the goal was to give residents of several households the ability to monitor the power usage of different devices of their households. Additionally to the raw power usage, standby times of devices are visualized and tips for energy savings are given according to the collected data from these households.

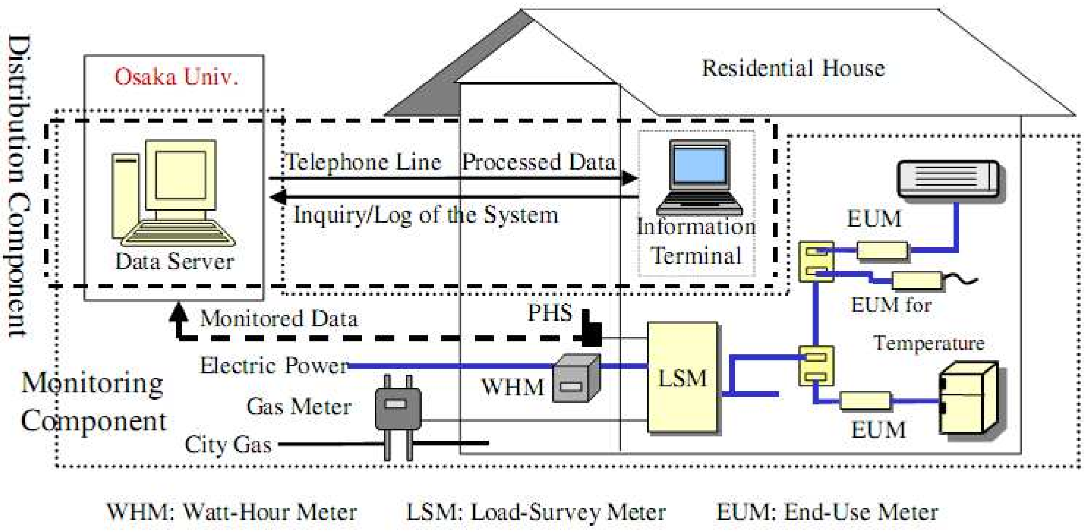

Figure 3: ECOIS II infrastructure[18]

The ECOIS II system consists of monitoring components, including a Load Survey Meter (LSM) for power and gas consumption measurement of an entire housing unit, an End User Meter (EUM), for electric power consumption of single devices (home appliances) and another one for room temperature. The data sent by the EUMs and the LSM are collected by a Personal Handy Phone System (PSM) and sent to a central computer located at Osaka University. The whole ECOIS II infrastructure is depicted in Figure 3: ECOIS II infrastructure.

The second component is responsible for distributing data back to an information terminal in every single household. The information terminal can also be used for sending feedback from the project participants to the central computer..

The last part of the system is the user interface for the information terminals, which can be seen in Figure 4 in a translated version. It visualizes energy consumption of single devices as well as of the whole household,

[18] T. Ueno et al, "Effectiveness of an energy-consumption information system for residential buildings", Applied Energy 83, 2006

differences to previous day(s), energy savings in Yen, tips for reducing power consumption of these devices and so on.

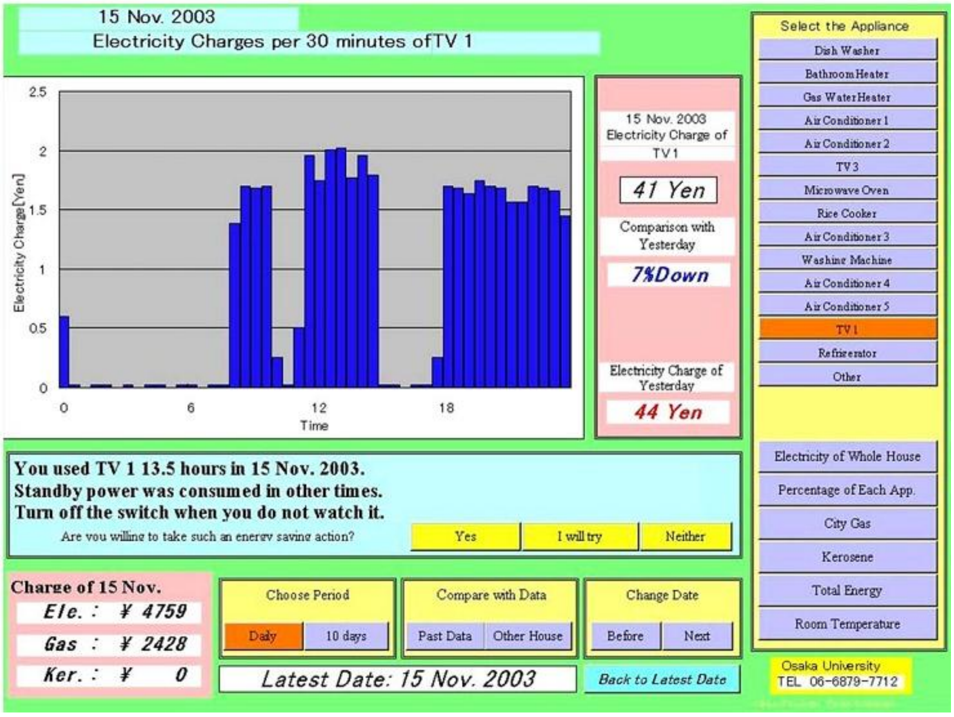

Figure 4: ECOIS II information terminal interface

The project spans 19 detached houses. Ten of them were equipped with the ECOIS information terminal; the rest was just measured to see the differences. The evaluation showed a frequent and regular access of the terminal in the first days of the study which slightly dropped the longer the study was going on. After approximately two months the number of operations conducted with the interface stabilized around ten per day. Group A – which had ECOIS information terminal installed – had an averaged reduction of electric power consumption of 5150 Watt hours (Wh) per day (minus 17.8%) and a reduction of gas consumption 4875 Wh per day (minus 8.8%). Group B's consumption of electricity shortened by 891 Wh per day (minus 4.7%) and consumption of gas increased by 147 Wh per day (plus 0.4%). The study considered a positive effect in energy savings when installing ECOIS II system.

2.5.2 PowerSaver

The project PowerSaver [FERSC2007] is led by the Institute of Pervasive Computing of Johannes Kepler Universität Linz. It shows the possibilities of motion tracking, presence detection and scene recognition by modern means. This project addresses the problem of energy waste by standby-modes and unnecessarily activated devices.

Device	TV	Laser printer	Satellite receiver	Multimedia center	Espresso machine
Energy consumption	83,20 kWh	105,60 kWh	138,79 kWh	96,40 kWh	185,00 kWh

Table 1: annual energy consumption of typical household devices generated in standby mode [FERSC2007]

Table 1 shows the massive energy usage of devices that are needed just a few minutes to some hours a day but are activated 24 hours a day, 7 days a week in some households. The data was ascertained in the year 2006 so the energy consumption of actual devices may be slightly different.

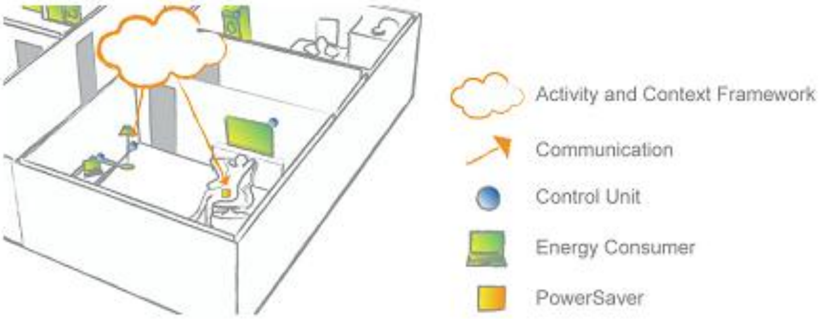

Figure 5: System Architecture of PowerSaver [FERSC2007]

The PowerSaver system consists of three parts. The first one is a wearable position tracker which could be used in everyday objects like mobile phones, key tags, shoes or in belt buckles. The second part is a network of stationary motion trackers. In its current state and for flexibility purposes the sensors are placed on scaffolds. These are positioned in houses and flats to cover the whole living area. The last part is called "Activity and Context Framework", which interprets the data gathered from the stationary and mobile sensors. For example it distinguishes between sitting, standing and walking and sends orders to the actuators (control units) which are connected to devices. A simple example is that it is not necessary to illuminate one or more rooms when nobody is in these rooms. This example can easily be extended to other devices like TV (deactivating background lighting to completely going in standby), radio or espresso machines.

The most advanced and new component is the "Activity and Context Framework" which is responsible for recognizing which activity the user currently is executing. It is a learning and adapting artificial intelligence that builds the unique core of the whole project. At current state the system can distinguish between more than 20 activities and may transfer devices into various energy modes.

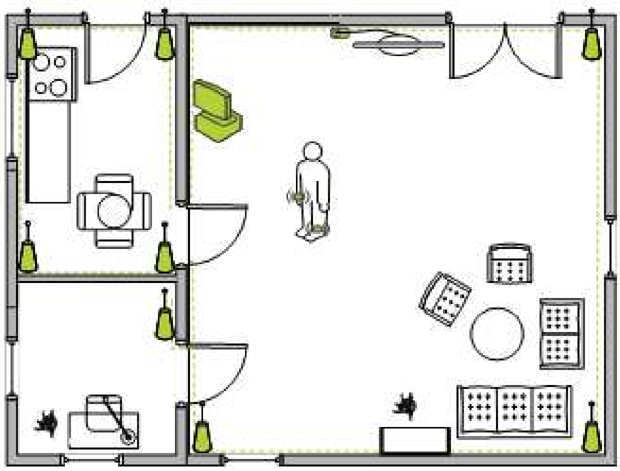

Figure 6: Sensors and Power Saver Center [FERSC2007]

In January 2010 a field study started using PowerSaver projects in different flats of volunteers to research the practical usage and get a better measurement on how much energy can be saved.

2.5.3 House_n (Massachusetts Institute of Technology)

The "*House_n*" spans a whole department at the Massachusetts Institute of Technology (MIT). The department of Architecture research group investigate how new technologies, materials and also design strategies affect living in a home. Two major initiatives started by "*House_n*" are "*The PlaceLab*" and also the "*Open Source Building Alliance*". The purpose is to develop key components for future buildings involving the manufacturers, builders, developers, designers and also the customer.

"The Place Lab" is a residential flat designed as an observation facility on how people interact with new technologies that are built in their home. The flat is occupied by volunteers for a given time with absolutely no personal contact to the researchers. The test persons and their actions are monitored by hundreds of sensors positioned in every room to achieve an authentic scenario for the residents and their daily living and routines. Examples for such sensors include motion sensors to track the position of the user as well as sensors on appliances to get to know in which context they are used. "The PlaceLab" is used to research new and innovative user interfaces for new ways to control a smart home's environment, ambient assisted living and e-health scenarios and save resources. For a better comparison of the persons' living patterns, participants can use a portable tool kit to monitor their living behaviors already before and also after the occupancy of "The PlaceLab". The MIT researchers use this smart home to possibly answer the following questions [MIT1]:

- What influences the behavior of people in their homes?
- How can technology be effective in the home context for long time periods?
- Can technology and architectural design motivate life-extending behavior changes?
- To what degree can measurements of activity in the home be quantified in a way useful for creating new computer applications for the home?
- How can technology be used to simplify the control of homes of the present and future, save resources, and improve health?
- What influences how people adjust to new environments?
- How do people learn in the context of the home?
- What new innovations for the home would most fundamentally alter the way we live our everyday lives?

Current projects that are pursued involve tracking and recognizing activities in daily living with ubiquitous sensors to detect medical emergencies, context-aware computing devices, portable low-cost wireless sensors (*MITes+*) for detecting motion and position and also medical values of the wearer (like heart rate or ultra-violet light exposure) or the development of ubiquitous computer interfaces. For example, a prominent project that was also tested in "The PlaceLab" is the "IBM Everywhere Display"[19] – a projector coupled with a camera that can convert every surface to a touch screen.

2.5.4 The aware Home (Georgia Institute of Technology)

In 1998, the Aware Home Research Initiative (AHRI) was formed at the Georgia Institute of Technology and built a model smart home in a common three-story house called "Georgia Tech Broadband Institute Residential Laboratory" that serves as a living laboratory for interdisciplinary sciences. The house is in operation since 1998 and research in it is still ongoing.

The current research is divided into three subjects. The first is "Chronic Care Management in the Home", which concentrates on assisted living for elderly and above all on supporting the communication and networking process between elder people or people with disabilities and other persons that live in the

[19] IBM, "The Everywhere Display Project", available on the Internet, URL:http://www.research.ibm.com/ed/, 2010-10-30

same house. The second one is "Future Tools for the Home", focusing on embedded and ubiquitous computing, sensing and actuation technologies as well as robotics and how they fit into a household and its routines. The third topic is called "Digital Entertainment and Media". Here, the research subjects range from usability and user interface design to security and privacy problems that arose with new technologies and the way media is presented currently.

Current projects include "Early Detection of Development Delay", which is intended to track, record and detect development milestones of children and help parents and healthcare providers noticing delays in the children's development like autism or deafness. The "Powerline Event Detection" senses the activities of the inhabitants by detecting the distinct electrical noise patterns in the wiring of different electronic devices such as lighting, television or coffee makers. Another interesting project is the "Gesture Pendant". The user wears a pendant with a wireless camera in it. When he makes gestures in front of it he is able to control e.g. the lighting, the home entertainment center or the kitchen sink. Also the system can identify loss of motor skills or tremor to detect possible health problems earlier. Also an energy consumption display similar to the ECOIS II project is on the list of research topics.

2.5.5 T-Com Haus

The „*t-com Haus*" is a smart home built by the enterprise *T-com* with the support of some partners (especially Siemens provided the house automation and most of the end user devices) and was officially opened on March 1st 2005. The technologies used here were already available on the market but have not been used (excepted are other smart home model houses) networked and in an overall concept. The "*t-com Haus*" was used as a public showcase and also laboratory where interested people could live a weekend in this house to see the advantages of networked modern technology in households.

Usage scenarios include the field of telecommunication and information (like delivering media for e-paper on demand, a virtual document safe online…), multimedia (house spanning mood management to control lighting, audio and video devices to the user's mood), entertainment (video/music on demand, virtual training courses …) and security. Of course T-Com enterprise presents oneself as a supplier of services that fit into a smart home rather than a smart home building company due to its field of operation. Also a low energy house was not the prime incentive for this building and not separately presented to the visitors but of course modern and intelligent white and brown ware devices were part of the home. The house's center piece is a PDA-like device that grants access to nearly every function in the smart home beginning with controlling shutters, heating or lighting, up to checking the status of various appliances whether it is white ware or brown ware or neither of these two classes. It even can be used as a remote control for the TV for example.

Interesting features presented here were the "family whiteboard", which is used as a central communication platform for the inhabitants, not only for communication outside but also inside the family structures. It collects messages from different sources like email, phone, SMS and so forth. Weather data can be obtained, a schedule for a specific cinema, or also news. Also short audio, video or simple text messages can be left for another person. As soon as the other one checks the white board the message is played. Mutually with a PDA device, this board is also a control platform for the whole house – obtaining status reports about white ware devices or controlling the automated visitor answering system. All features are accessible with this device. The family whiteboard was implemented as a touch screen mounted on the wall. As the PDA device is a central appliance in this house some features of the family white board can also be accessed with it. Also the room spanning mood management which allows specific settings for lighting (intensity, color, specific luminary) and background sound is a factor that helps people recognizing the smart homes advantages.

2.5.6 inHaus (Innovationszentrum der Frauenhofer-Gesellschaft)

inHaus[20] is a platform established by the *Frauenhofer-Gesellschaft* linking business partners and researchers in the field of home automation, building technologies, facility management and health care. The scope also includes hotel business and events as well as office and service. Therefore, the first inHaus building (inHaus 1) was set up in 2001 and had its first operation phase until 2005. The first inHaus can be seen in Figure 7. It is clearly visible, that it is built as a residential standalone house and according to that the research interests are mirrored.

Figure 7: inHaus 1 - exterior view

The *inHaus 1* – also called Smart Home – accommodates a living, bath, kitchen and workshop laboratory. The house includes tele-medical appliances in the sleeping as well as the bathing area. The bath room is also equipped with intelligent sensors for optimal airing and air quality and individual water management. It even has an "intelligent garden" (networked watering system, automated lawn mower ...) and a multimedia car as well. Due to its purpose, its indoor look and devices are in a constant change. Despite the initial intentions the building serves as a "demo" house for Smart Homes too. But its primary purpose is to allow the development and testing of new products in the sector of house automation and smart living. An important research task is to conduct acceptance workshops and test living phases (up to three months) in the *inHaus 1*.

Due to the success and high demand of the *inHaus 1*, the *inHaus 2* was set up in 2008. The experience and technologies that proved well in the first house were adopted directly. The second building set its focus on hotel business, healthcare and office labs instead of the residential area. The *inHaus 1* having a rather common look – not different from a typical residential single house, the *inHaus 2* looks quite futuristic in its interior and exterior which can be seen in Figure 8.

Figure 8: inHaus 2 - exterior view

The more famous project that is conducted in the inHaus initiative is for example the Amigo Project[21] financed by the European Union which's goal is to develop an integrated middleware spanning all areas of technical devices used in a house, including PC, white and brown ware devices, mobile devices, telecommunication or home automation appliances. The purpose for this project is to face a challenge already described – the interoperability of devices from different producers with different control networks.

2.5.7 SmartHOME (Universität der Bundeswehr München)

Simply called SmartHOME[22], this building was built and managed by the institute of Sensorik and Measurement Systems of the "*Universität der Bundeswehr München*" since 1996, having its primary objective in testing new *SmartSensor Systems* for better energy efficiency and living quality as well as increasing security. It is equipped with smart power devices gaining electricity from renewable energies, advanced sensors (in- and outdoor) and measurement and automation systems and of course digital networks and bus systems of home automation. The house is used for putting research work into practice,

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[20] Frauenhofer Institute, „inHaus Homepage", URL:http://www.inhaus-zentrum.de/site_de/, 2010-08-05

[21] Information Society Technologies, "Amigo Homepage", URL: http://www.hitech-projects.com/euprojects/amigo/, 2010-09-22

[22] "Universität der Bundeswehr München", "SmartHOME Homepage", URL: http://www.unibw.de/eit8_2/forschung/projekte/shfilm, 2010-08-14

information events and visitor tours. The goal is to develop a zero energy house or even a plus energy house, being independent of fossil fuels not just on annual average but on every day and hour of the year.

The research focus includes several topics like developing cheap and robust indoor and outdoor sensors or energy efficiency of different airing strategies (e.g. automated ventilation regarding CO_2 level). Also windows with switchable glazing, which reduce sun insulation and consequentially the heating up of rooms is a topic that is researched. Also a window called "Klimafenster" was developed that can open, close and tip automatically to provide fresh air. Further projects include remote controlling of different devices and house functions with gesture recognition (SmartPointer project) or exact user tracking and motion detection.

A full list of current and past projects can be found at [SMART1].

2.5.8 iHome-Lab

The iHome-Lab is a smart building built and managed by the Hochschule of Luzern in Switzerland, where more than 300 single projects are currently running. It is designed to be a think factory for innovative living-scenarios, a joint venture-research platform, a place to perform usability and acceptance tests, an establishment to serve as an interdisciplinary network and also to improve the public's sensibility for smart home projects. The main interests are advanced metering infrastructure (smart metering, load management), human machine interfaces, ambient awareness and ambient assisted living, home network technologies (e.g. KNX, ZigBee), Web Enabled Services, Internet of Things, Embedded Plug&Play, Infotainment, Edutainment and many more. Figure 9 shows the exterior of the iHome Lab building.

Figure 9: iHome Lab Front View

A project that is conducted currently is the *eMeDi* (a German abbreviation for *Energiemessdimmer* or energy measuring dimmer in English) for example. The eMeDi device measures the energy consumption of a single device and sends the data wirelessly to a central display. The user has a detailed overview of the energy consumption and is able to optimize it. The eMeDi can also dim or turn off the device it is connected to. Other current projects involve automated fall detection sensors with alarm functions (WeBee 3G) or automated localization and context awareness of room automation devices (easyLoc). A full listing of current projects is available at [IHOME1].

2.5.9 IQ150

The IQ150 [IQ1501] is a small smart home built and managed by students and employees of "F*reie Universität Berlin*". Different topics in home automation and smart homes are discussed and experiments that are also dealt with in courses can be conducted there. The main interests are new heating systems, ambient intelligence, how to ensure problem-less interconnection of various commercial systems with different control protocols, as well as green cars and robotics. The

Figure 10: IQ150 living room

first field test was completed in November 2009 and a new building is expected to be finished in 2011 or 2012 concentrating on energy consumption and sustainability. This building will also be publicly accessible as an exhibit.

The IQ150 smart home uses the most modern technology that is currently available on the end consumer market. Because the funding of this project was purely from private means the main focus was to keep the costs low. The home automation system was provided by the company bticino[23], which is additionally accessible by an adapted version of the *XBOX Media Center* (XBMC) due to its dynamic extensibility and public domain. It allows the inhabitants to control every single device (e.g. white and brown ware) and house function (e.g. HVAC, shutters …) from a display in every room. Therefore, a schematic ground plan is accessible via the XBMC system where every function and device that is available or situated in the room can be controlled. An eye catcher is the couch table with an integrated touch screen and computer and can be seen in Figure 10. It is useable in the same way a normal PC is useable, to obtain information from the Internet or play games with multiple users – in fact this can be a replacement for board games.

[23] http://www.bticino.com/index.php

3 Energy Efficient Use Cases

The main and most extensive part of this thesis is presented in this chapter. Due to the massive increase of energy consumption of households the area of home automation is also being worth of a broad operation in the residential area. Another important fact is that automation equipment like sensors and actuators are becoming affordable by private persons, which also applies to computers and computing equipment. For example, today it is not unusual that a server is situated in a household that may even run 24 hours, 7 days a week. This builds the basis to overcome the next obstacle – integrating a smart home server in every household. After that, setting up a reliable and efficient artificial intelligence in such a home will be the next step. In consideration of these reasonsm this chapter contains a selection of possibilities that an increased automation and networking in private households is offering.

This chapter is structured into 3 parts. The first part contains four user stories which describe typical situations in households in an informal way. The first two concentrate on a single person household. The last two focus on a characteristic family household with four family members. After each user story a graphical representation of this user story in an UML use case[24] as well as an UML activity diagram is given. Additionally, a list of all use cases that appear in the user story follows that and a short description in which situations they are triggered. The decrease in energy consumption of the given household is the goal of nearly all of them, but some also increase the comfort of the inhabitants or the security and safety. The purpose of these user stories is to give the reader an idea on what a smart home is capable of in supporting the user in his daily routines, saving energy simultaneously or increasing comfort, safety and security.

The second part of this chapter includes a list of energy saving use cases structured in the main fields of home and building automation like HVAC, lighting, white ware devices and appliances or sanitary. As contrasted with the user stories, the use cases are a formal representation of the abilities of a smart home. The quantity and complexity of the use cases is extremely different. Some of them can be covered by some sentences whereas others need several pages to be described sufficiently. Larger use cases like "*Ensure Air Quality*" or "*Ensure Visual Comfort*" have some smaller ones incorporated that either are an addition to their functionality or examples for a special usage of them. The last part of the second chapter is a collection and description of all diagrams that are used by several other use case diagrams.

[24] Referenced use cases are not connected to all actors due to increase overview

3.1 User Stories

This chapter contains the four user stories, describing daily routines and situations in single person as wells as family households. First an informal textual description is presented, followed by a use case and an activity diagram. After that, a short explanation of the different use cases is given and the context in which they are used here.

3.1.1 Single Person Household - Morning Routine

This User Story represents a typical morning on a workday and outlines how technology in a smart home facilitates the routine tasks that a house inhabitant goes through in the morning, starting before he wakes up until he leaves his house.

3.1.1.1 User Story

The alarm rings and the user wakes up. The sun is already brightening the room, which helps him getting up easier. Although the shades were closed during the night to prevent heat loss, the blades were opened bit by bit before the alarm rang. Like every morning, his first act is the way to the bathroom. Because the corridor has no windows and is sparsely illuminated by natural light, the lighting is turned on automatically as he enters it. The smart home closed the bathroom door during the night because the user likes his bathroom warmer than the rest of the house – especially in the morning. As the alarm rang, the house began preheating the water in the shower to ensure instant well tempered water out of the shower head. While he is in the bathroom the radio program that woke him up followed him from the bed room, into the corridor and now into the bathroom. The speakers in the other rooms are disabled as he leaves a room and the ones in his current position are turned on without any interruption of the music. While the water is pouring out of the shower head the volume rises so the music is audible fine.

Because the system knows the average time he needs from the alarm ringing until he is entering the kitchen, it is timely powering up the coffee maker and the water in the machine is heated. When the user finished washing and dressing the coffee maker has heated the water enough and if it recognizes an empty cup under its nozzles the coffee flows into it. When the user comes into the kitchen, the coffee is ready to drink. During breakfast he reads the news on his iPad[25] or any other tablet pc. On the same device he can obtain a status report about any uncommon events that happened during the last night or another time span. For example the system reminds the user that windows were left open, so it shut them. It also states that the washing machine and dryer have finished their program and the laundry is ready to take out. It would also report if a problem had occurred in the HVAC system or other household appliances.

After breakfast the user is ready to go to work. As he leaves the house all electric devices (radio, TV, digital picture frames, coffee maker …) are shut down. Windows and doors that were left open are closed. Even the water conduit is closed off to reduce loss of water by dripping faucets. According to the user’s settings, the smart home computes an optimal airing strategy for this day immediately after he has left the building. The rooms are at the moment optimally tempered and the temperature difference between inside and outside the house is just around 5°C, so the duration of the airing is not as critical as on hot summer or cold winter days, due to the fact that the indoor temperature is less influenced by the outside air temperature. Since the user is no longer at home, the windows will not be opened completely; they are just tipped to prevent humans or animals to get into the house. The system checks the wind direction and according to the floor plan opens specific windows to achieve optimal air exchange. After the CO_2 level, air humidity and pollutants like tobacco substances or fumes from cleaning substances have reached their predefined values airing is accomplished and the windows are closed again.

[25] http://www.apple.com/de/ipad/

3.1.1.2 Diagrams

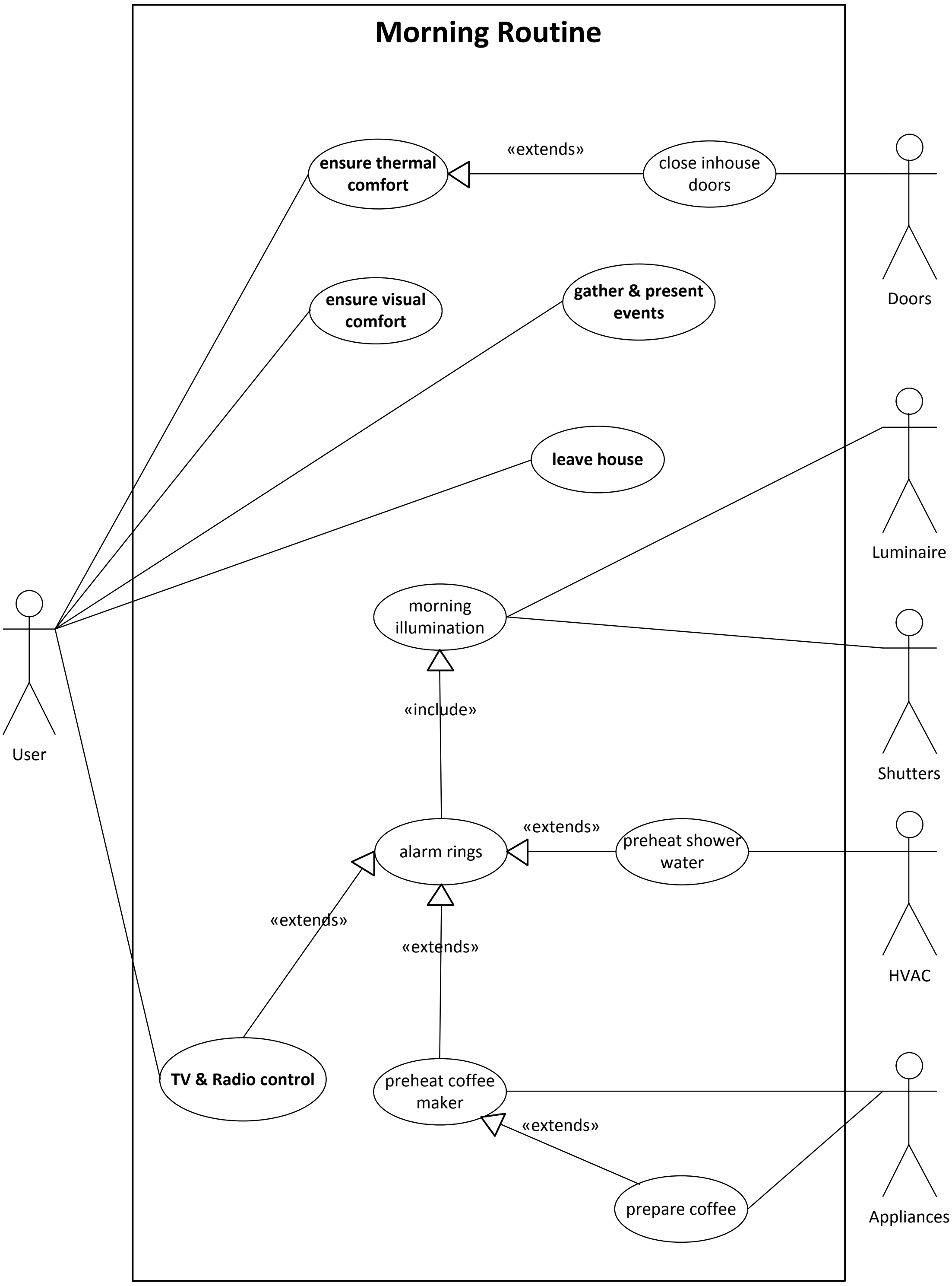

Diagram 1: Morning Routine Use Case Diagram

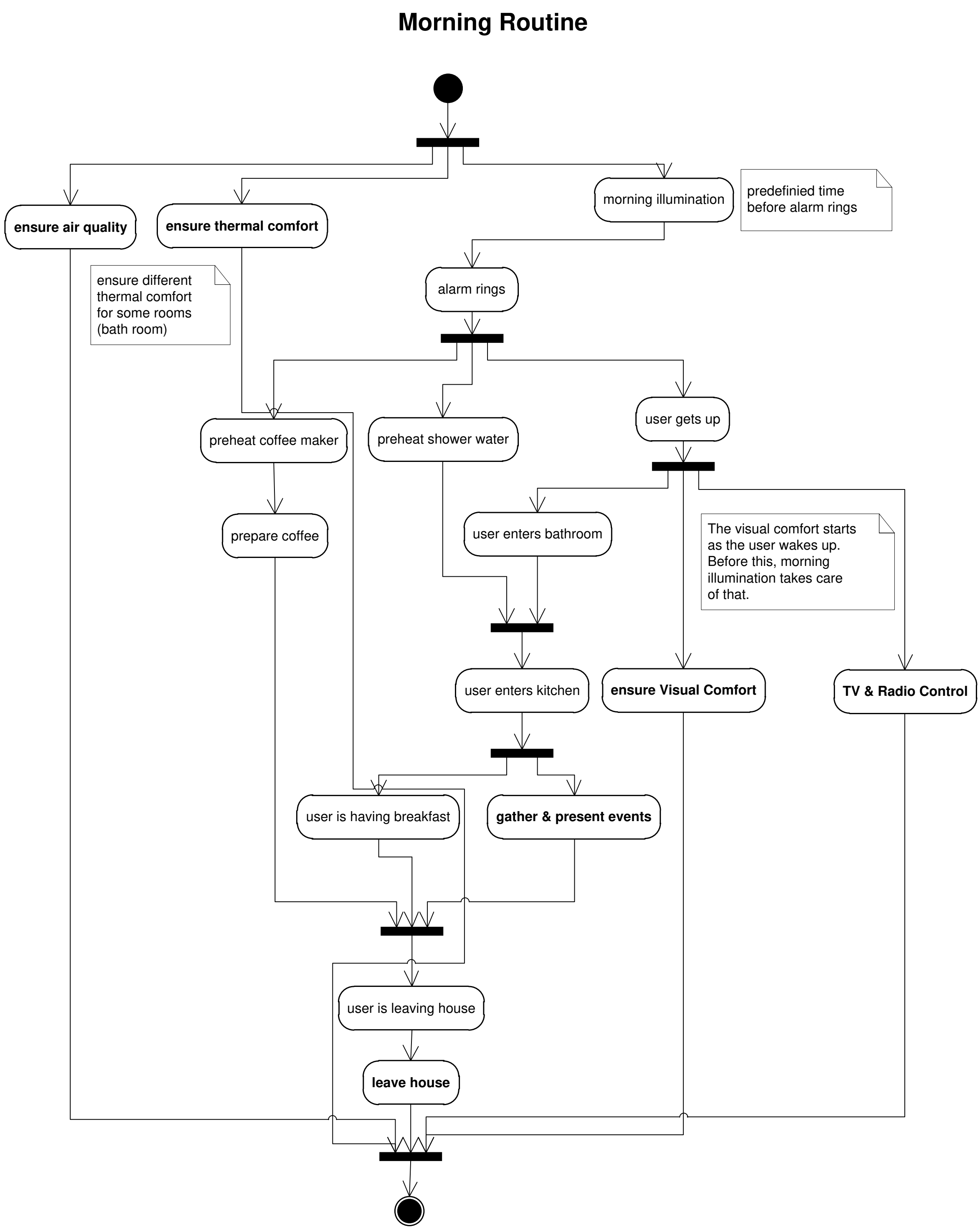

Diagram 2: Morning Routine Activity Diagram

3.1.1.3 List of related use cases

The following list contains all use cases that are part of the first user story:

Morning Illumination

This use case represents a method to wake the user up gently with illuminating the bed room bit by bit. A detailed description can be found in chapter 3.2.6.2.

Preheat coffee maker

In morning routine the user gets up and after taking a shower he enters the kitchen. As the system already knows from the historical data how long it takes him from getting up to start breakfast, the coffee maker is already turned on and the water is preheated. It can even prepare the coffee in a cup in advance if there is one sensed under its nozzles. The full description of this use case can be found in chapter 3.2.7.1.

Ensure Thermal Comfort

A part of the use case E*nsure Thermal Comfort* is mentioned here in this user story. The thermal comfort is regulated the whole time but there are certain triggers that cause a change in the smart home's strategy or also special conditions for different rooms. The user enters the bathroom in the morning, which was already perfectly tempered to his preferences. It is quite warmer than the rest of the house and therefore the system closed the door after the user went to sleep the evening before. The system reacts again when the user leaves the house. Then the tolerance for room temperature is loosened, so that the heating can be reduced in winter as well as the air conditioning in summer. The description of the whole use case is described in chapter 3.2.3.1.

Ensure Air Quality

Of course the house cares for the air quality (CO_2 level, humidity level etc.) the whole time but here a special aspect is mentioned. After the user left the house the system starts a complete air exchange of the house. The whole use case is illustrated in chapter 3.2.4.1.

Ensure Visual Comfort

The use case *Ensure Visual Comfort* is briefly mentioned as he enters the hallway and the system automatically turns on the luminary to his preferred brightness in the morning. As this is just a small aspect of this use case, the full description is available in chapter 3.2.6.1.

Leave House

This use case is primarily intended to increase the user's comfort. Another positive side effect is an increased security and also reduced energy efforts. It starts at the end of the user story when he left the house and goes to work. The system shuts down unnecessary energy consumers and closes windows, doors and the main water conduit. Also a complete air exchange is executed. The whole description can be found in chapter 3.2.4.2.

Gather & present events

Also a use case called *gather & present events* is mentioned, which sends collected data about personalized events - like the fact, that he left some windows open before going to sleep or that the washing machine finished its program – to his iPad device. A full description of this use case is available in chapter 3.2.11.2.

TV & Radio control

The last use case that is mentioned is that the radio or music that the inhabitant listens to follows him through several rooms. This does not just serve the comfort of the user but it also reduces energy consumed by speakers, radio or any other music station. When the speakers of another room take over the task to play the music or radio program the speakers in the previous room are shut down. But not only the power status of these devices is controlled, also the loudness is automatically set to the user's preference. For example it prevents that the radio in the morning is too loud just because the last time he heard music that was his last setting. The full description of the use case is available in chapter 3.2.8.1.

3.1.2 Single Person Household – Coming Home

This user story describes another typical situation in a household. The inhabitant is coming home in the evening from work, relaxing with a cup of coffee and watching TV and doing some domestic tasks afterwards. The smart home is increasing his comfort whilst saving energy.

3.1.2.1 User Story

After a working day in a hot summer month the user finally reaches his home. As the smart home expected he arrived just around the time he gets home nearly every day during the week. As the house knows that nobody is at home when the inhabitant is at work the heating and airing was reduced to a predefined minimum. To reach the most comfortable temperature and air quality for the homecoming of the user the smart home has to calculate the appropriate time to start airing and heating. While the HVAC system brings the rooms to its optimal thermal level, it starts raining outside and the temperature level falls down. The smart home recognizes that and instead of letting the air condition cool the rooms the windows are tipped to get the cool fresh air into the house.

The smart home welcomes the user home with relaxing music, telling him, that two people called and a delivery man wanted to leave a parcel during his absence. Because he likes drinking a cup of coffee after coming home, the coffee maker already began heating the water and short after he enters the house the coffee flows into a cup. While drinking his coffee in the living room his ePaper or tablet pc (e.g. iPad) shows him a detailed report of the missed calls and any uncommon events in his absence and allows him to read any of his subscribed magazines. Because the user is very concerned about ecology he can even check the power consumption of his electric devices and the whole household. The system informs him that he can reduce his energy efforts in heating periods by six percent when he reduces the room temperature by 0.5 degrees Celsius and save a lot of CO_2 emissions and other nature-damaging gases. He turns on the TV to watch a show while enjoying the rest of his cup of coffee.

After a few minutes he feels a crave for another cup. He leaves the room and enters the kitchen to fetch one more coffee. As soon as he walks out of the living room the background lighting of the TV is shut down. Also the speakers will not play a sound, because the audio output is redirected to the speakers in the kitchen. In the kitchen he remembers that his *“iPad”* also stated that the washing machine and dryer are ready, so he gets the clothes and puts them in his wardrobe. The smart home recognizes that this action may take a while so it shuts down the TV completely – though the sound is still played and follows the user through the different rooms. The TV in the bedroom is turned on automatically and lets him see the show while he places his clothing in the cupboard.

He recognized that his cloth basket is already filled until the top so he decides to fill the washing machine once more. As he is not in a hurry with washing these clothes he lets the smart home decide when to turn on. As the washing machine, as well as the dryer, are energy-intensive devices it is crucial for a low power bill when to turn on. The system checks the weather forecast for the next day and sees that it will be a clear day, so it is very likely that there is enough sun insulation for the photovoltaic power system to reduce the power needed from the electricity distributor. If the next day would be cloudy, the system may have started the device during the night when power is cheaper.

After that whole domestic work he deserves some relaxing TV program. A short time after he sat down the door bell rings. A Picture in Picture appears on the screen showing him who is standing outside. It seems to be a delivery man, so he opens the door and takes the parcel.

3.1.2.2 Diagrams

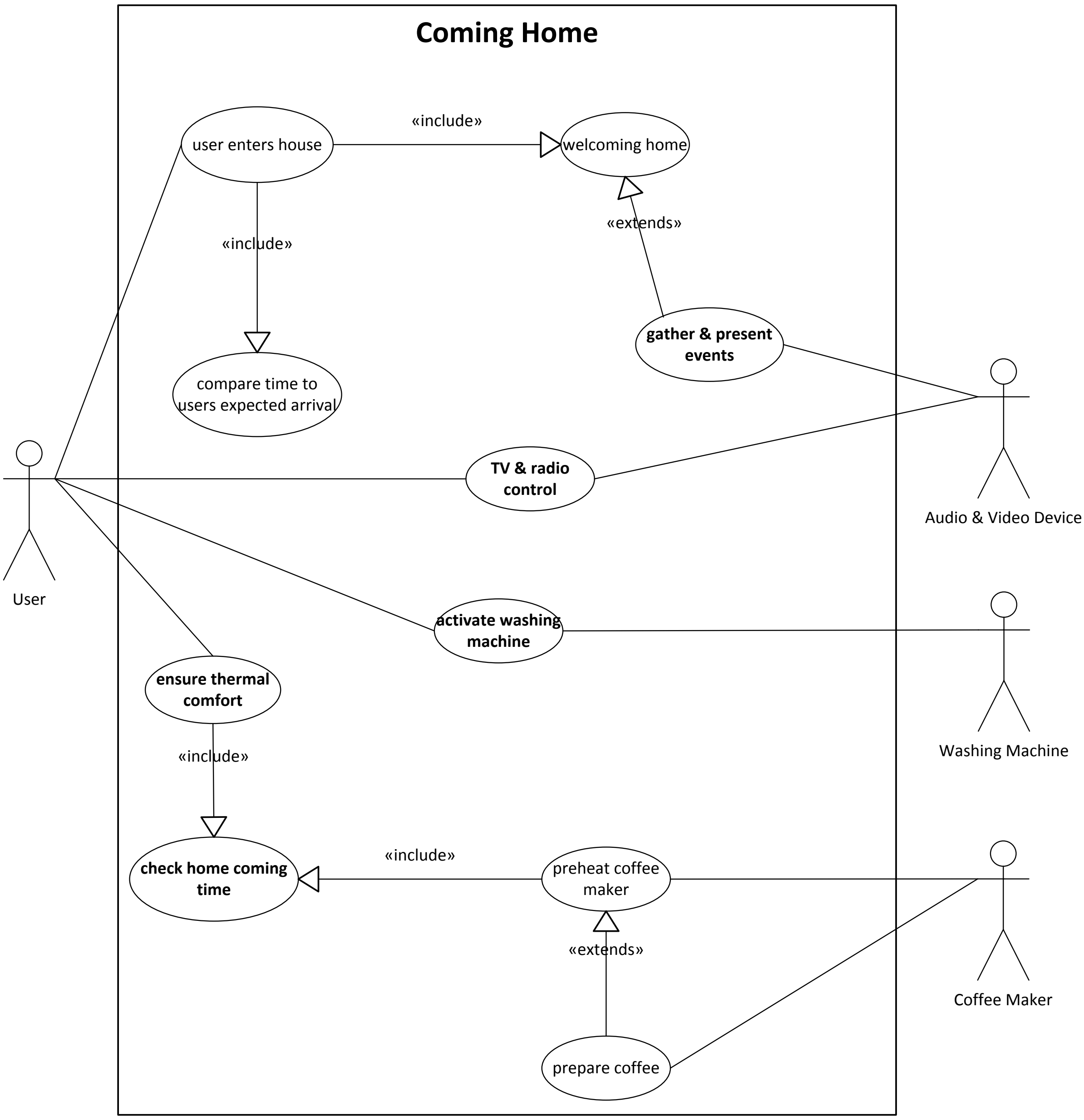

Diagram 3: Coming Home Use Case Diagram

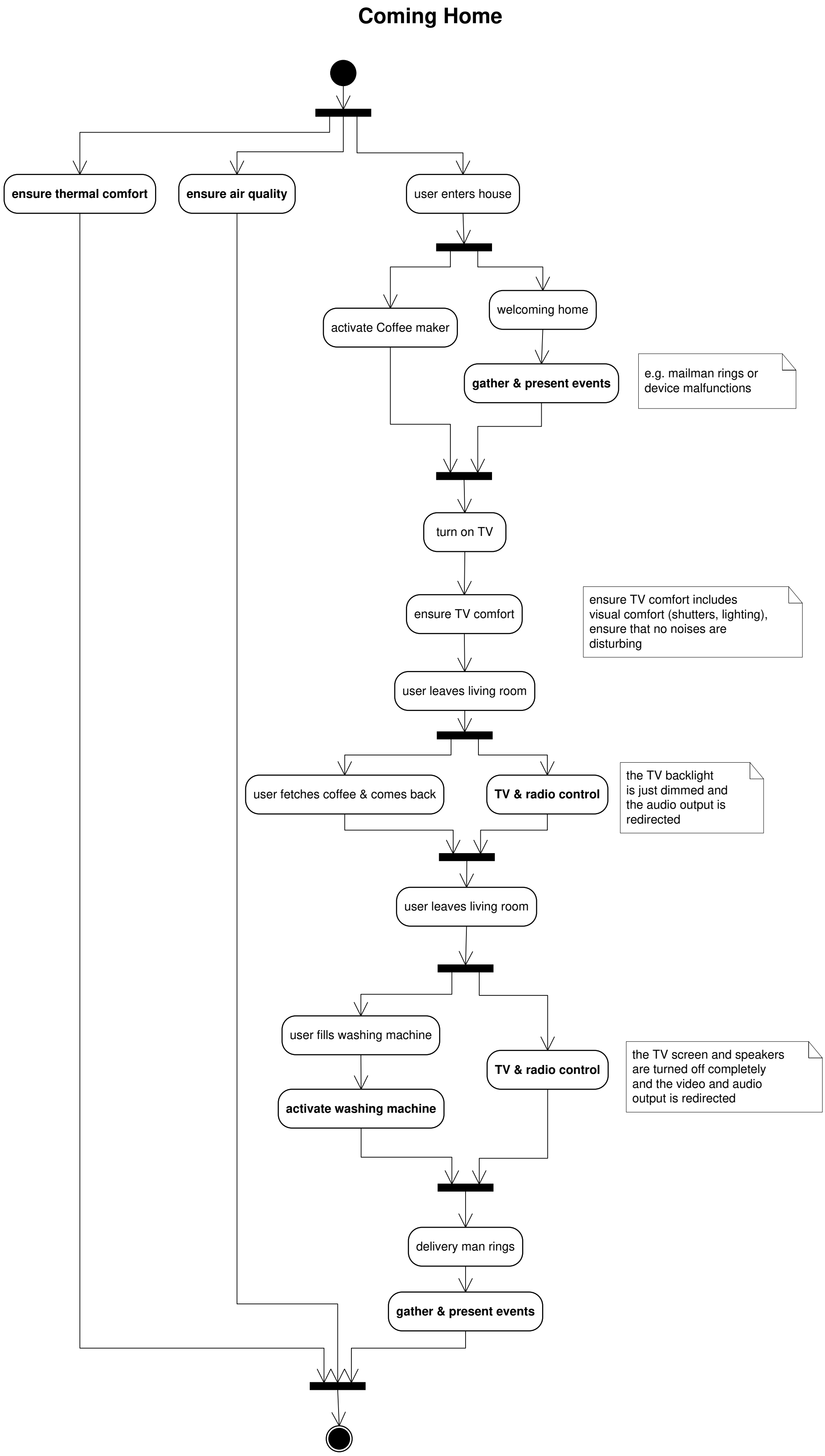

Diagram 4: Coming Home Activity Diagram

3.1.2.3 List of related use cases

Ensure Thermal Comfort

An aspect of this was already mentioned in the previous user story, namely the heating of single rooms and also the closing of this room's doors. Here, the smart home provides a perfectly conditioned room according to the user's preferences as soon as he enters the house. The whole description of the use case is in chapter 3.2.3.1.

Check Home Coming Time

This use case is used by "E*nsure thermal comfort"* to calculate the correct time the HVAC subsystem has to be activated to achieve the user's thermal preferences. The corresponding description and diagrams can be found in chapter 3.2.11.1.

Activate Washing Machine

In order to fulfill some domestic work the user fills the washing machine and activates it. The smart home calculates the most efficient and cost saving time to start the washing machine. The detailed use case can be found in chapter 3.2.7.4.

TV & Radio Control

This use case was already briefly mentioned in the first user story. Here the sound as well as the video signal from the TV program is following the user through the different rooms. The original TV display and speakers are shut down to save energy. A more detailed description can be found in chapter 3.2.8.1.

Preheat coffee maker

This use case was already mentioned in the first user story and can be found at chapter 3.2.7.1.

Compare time to users expected arrival

As the user enters the house, the system compares the current time with the calculated arrival time from *check home coming time* to improve future predictions (i.e. learning capability).

Gather & present events

In the second user story the user is welcomed with a list of events that happened in his absence like that the delivery men visited to deliver a parcel. Also he is obtaining a detailed report about the house's different energy consumers. So the inhabitant can check the power consumption and analyze which devices are wasting a lot of energy and may be replaced with newer ones. By example the house could compute the energy consumption of the older fridge over the year and informs the user how long it takes until it pays off to buy a new one of a specific energy class. As an extension for this, the smart home can give advices in reducing energy efforts of specific devices and provide the inhabitant with more ecological consciousness. Information on this can be found in the project ECOIS II in chapter 2.5.1 . The complete use case "G*ather & present events"* is in chapter 3.2.11.2.

3.1.3 Family Household - Sunday Morning

This user story sets its focus on a family household having breakfast and lunch together on a Sunday. The smart home takes care of a comfortable room climate and supports them while cooking lunch.

3.1.3.1 User Story

The blinds are slowly opening and the sun rays begin brightening the room more and more. Since mum and dad are not getting up early before dawn – like during the week – and it is not cloudy outside, the indoor lighting need not to be turned on to gain sufficient light in the room when the alarm rings. Not all blinds of the house are opened at the same time – the ones in the kids' rooms are still closed, due to the fact they prefer to sleep longer on Sundays. Normally, the parents listen to their favorite radio program during the week, but on weekend they prefer it quiet and calm so bird tunes and ambient sounds are echoing from the speakers as an alarm. Typically, the sounds would follow them into the corridor but as the kids are still sleeping no sound is played as they leave the bedroom. In the bathroom the sounds are still very low but as they close the door, the volume rises.

While they are eating breakfast the kids finally woke up and joined them. As everybody is up now and gathered in the kitchen, the system begins evaluating its airing strategy for the day. It has to be assured that there should be as less draft as possible, because it will reduce the comfort of the inhabitants. The common weekday airing plan is modified. All the windows are opened that will not cause a draft that reaches the kitchen – therefore, the windows there are not opened. When the airing for the whole house is finished the system tips the kitchen windows until the desired air quality values are reached. But as long as the daughter is in the kitchen, who always freezes when windows are open (despite the outside temperature), the system decides to wait until she leaves the kitchen. It is a warm summer morning and the weather forecast says that it will get quite hot this day. To prevent the rooms from heating up the shutters are closed as long as nobody is in the room. In the kitchen – to grant enough natural lighting and a good view – the windows are slightly tinged instead as a compromise between heat isolation and comfort.

As it is tradition in this household, the parents begin preparing an opulent lunch while the kids are cleaning up their rooms. When the food is in the oven and the soup on the hotplate they can concentrate on other things while the system monitors the food. Before they leave the room the system notifies them that there is no cap on the soup pot. The father sits in front of his computer, reading the news and checking his emails. After a while a message appears on the screen that the soup will boil over soon and the heat of the hotplate is reduced. Because his attention is already drawn to the lunch he checks the status of the food in the oven via his computer. The smart home gives an estimation on how long it will take until it is ready. As there are just 15 minutes left he decides to finish reading the news and starts setting the table. When the food is ready the next speaker notifies him and also his wife about that fact. Also the kids are notified by a message on the TV.

After lunch they already planned visiting relatives. In their family calendar they quoted that they may come home late. When all are standing near the door the system notifies them that the backdoor as well as a few windows are still open. They now have the choice to close them manually or let the system do that automatically. Because they are not in a hurry the father closes the backdoor and also the windows in the living room. As they leave the house the system knows that it has to activate the presence simulation when it gets dark. It turns on lights according to the inhabitants' usual behavior at night, activates the radio or plays chatter and other sounds from the speakers to repel potential burglars.

3.1.3.2 Diagrams

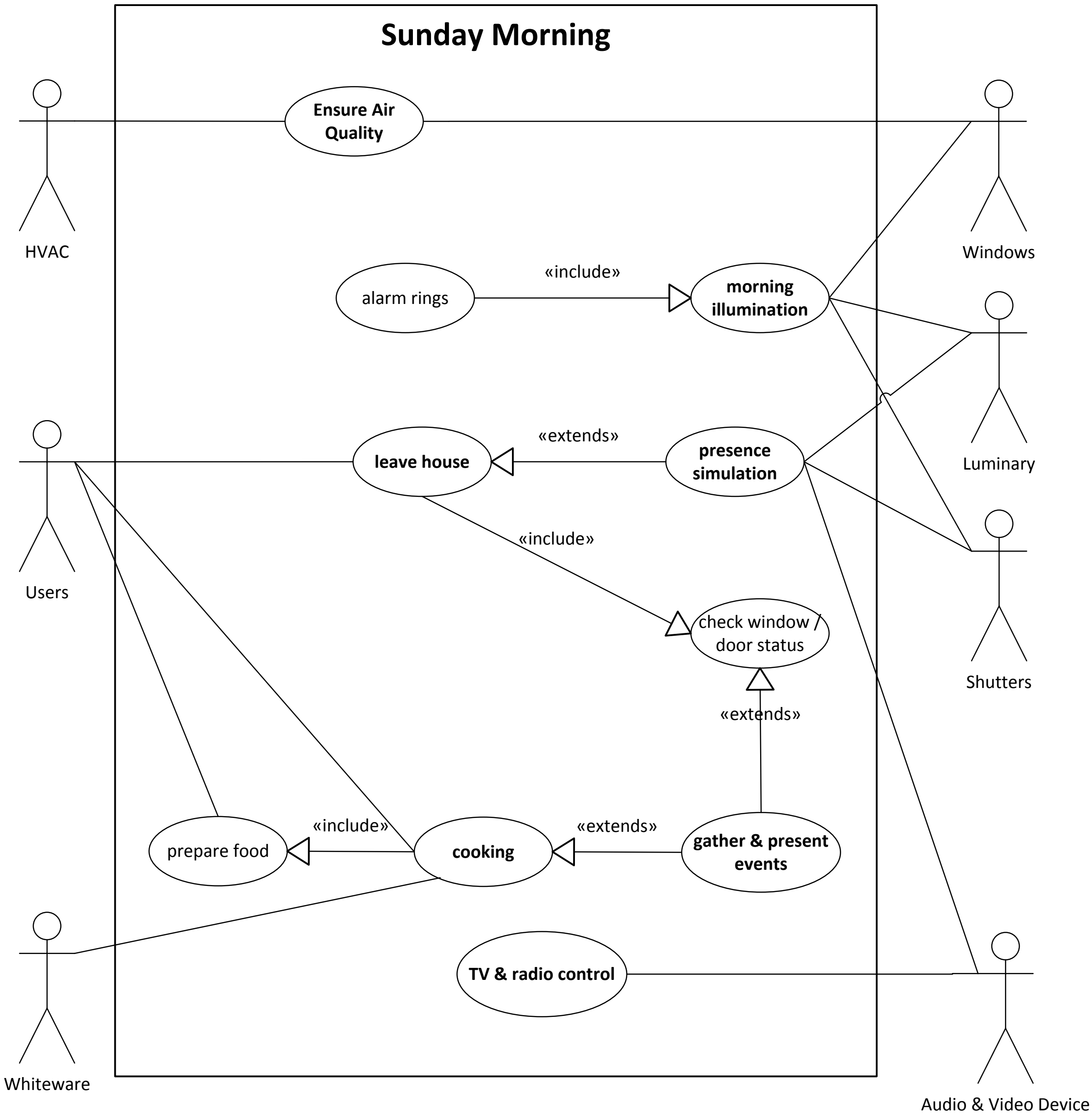

Diagram 5: Sunday Morning Use Case Diagram

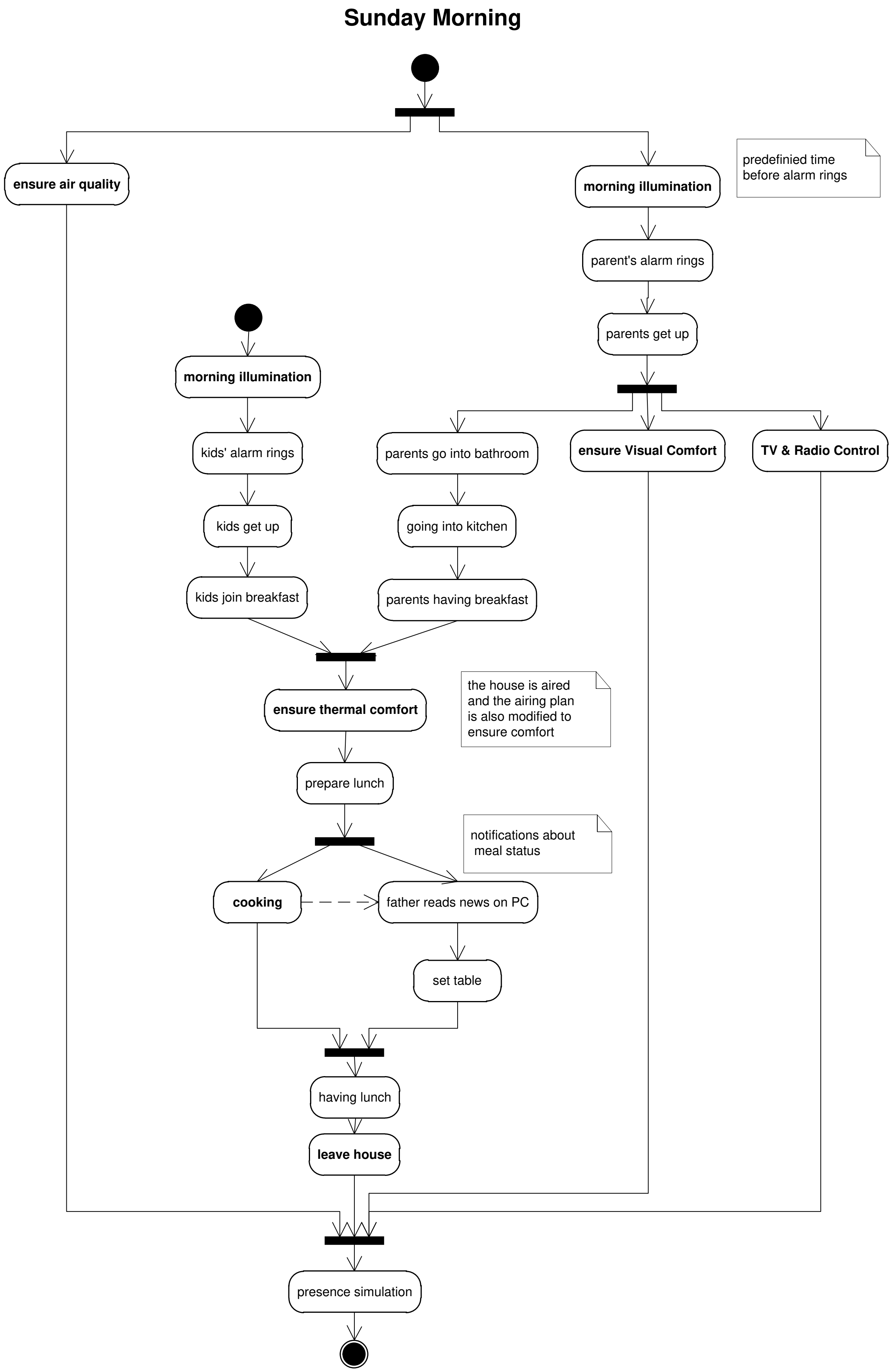

Diagram 6: Sunday Morning Activity Diagram

3.1.3.3 List of related use cases

Ensure Air Quality

Besides caring for a convenient air quality the whole time, the use case “Ensure air quality” is used especially as the family is having breakfast together. While airing the whole house the kitchen is left out to ensure that there is no draft. To fulfill the user’s preferences the window in the kitchen is just tipped. The whole use case is described in chapter 3.2.4.1.

Morning illumination

Though already described in the first user story an extended version is mentioned here. Instead of caring for a convenient wake up in one room, multiple rooms are illuminated in the morning at different times with different preferences. The complete description can be found in chapter 3.2.6.2.

Notify user of open windows/doors before leaving

Before the family leaves the house, the system notifies them of any open windows or doors. If the father had not closed them, the system would have done it automatically. The complete description can be found in chapter 3.2.5.1.

Ensure visual comfort

There are a lot of aspects mentioned that are collected in the use case “*Ensure Visual Comfort*”. Of course the smart home always checks if the user’s visual comfort is served. During breakfast the shutters go down as the sun insulation is getting too high. This is primary done to reduce cooling efforts in hotter periods. As the family is gathered in the kitchen the window there is just tinged to increase the visual comfort as well as serving energy efficiency. The use case is described in chapter 3.2.6.1.

TV & radio control

As the parents are standing up the radio program does not follow them through the house to avoid disturbing the sleeping children. When the bathroom door is closed the radio sounds are played again. The whole use case can be read in chapter 3.2.8.1

Presence simulation

As the family leaves the house the presence simulation is activated to deter burglars form breaking into the house. The use case is described in more detail in chapter 3.2.10.2.

Cooking

The procedure of preparing and finally cooking a meal includes several small use cases that are collected in this one. After the parents prepared the food, put the soup onto the hotplate and the meat in the oven they leave the kitchen. As they turn on the hotplates, just the area which is covered by the pots is heated. Before the grownups leave the kitchen the system checks if all pots have a cover. During the whole cooking process the system monitors the food if it is not over boiling or getting burned. All use cases and features that an oven in the smart home provides can be seen in chapter 3.2.7.2.

Gather & Present Events

This use case appears several times in the story. First the system notifies the family that the soup will boil over soon and a few minutes later that lunch is ready. Also as they want to leave the house the system checks if any doors or windows are left open and notifies them. More details can be found in chapter 3.2.11.2.

3.1.4 Family Household - TV evening

This user story follows the activities of a family on a typical evening. They gather in the living room, watch TV together and one family member is taking a bath while the intelligent home is increasing their comfort and reduces the amount of manual tasks.

3.1.4.1 User Story

It is a pleasant fall evening and the family father goes into the living room planning to watch a film. Because the position of the sun is already low it shines directly onto the screen causing considerable reflections. The system recognizes that and as soon as the TV is turned on, the shutters are going down. Until now the kids are listening to music in their rooms, which is quite noisy in the living room. At the same time the TV is turned on, the loudness is lowered to a predefined maximum, so the father can clearly understand the sound from the TV. The kids are notified about the reason the music volume is turned down on an activated screen in their room. The husband's wife likes to join him though she is not interested in the film. So she takes a seat at a table near a window and reads a book. As she needs the room to be brighter for reading, the blades are set to guide a part of the sunlight to the ceiling to brighten up the room. As it is still too dark, she rolls up the shutter at the window next to her a bit.

After some time the mother decides to take a bath, as she is not as interested in the book as she thought. She opens the faucet at the bath tub and the system recognizes that she plans to take a bath. It checks her stored preferences. The woman leaves the bath again and starts reading her book further in the living room. Meanwhile the smart home fills the tub to her preferred water height and temperature. A few minutes later, a message appears on the edge of the screen that the bath is filled completely and also an acoustic notification sounds from the speakers in the room. She notices that but first wants to finish the current chapter of the book. Three minutes later, the system notifies her again that the bath is already prepared. She finishes the last paragraph and heads off to the bath room. As she leaves the room the shutters are going down again. Not because the sun causes reflections on the TV, but this time it is already completely dark outside. They are closed that nobody can watch the people inside the house from the street side.

While the mother was bathing the kids joined the father in the living room. The room temperature was around 20° C because he is not sensitive to coldness. However, both kids prefer it slightly warmer – especially when watching TV in the evening – so the room's temperature increases slowly to 22° C. After a while, the father feels hot and nearly starts sweating. Looking at the room's temperature he knows the reason. He reduces the temperature to 21° C as a compromise and sends the kids to their rooms to fetch a pullover or a blanket. This fact is recognized by the system and stored for future similar events.

Due to the fact that the whole family gathered in the living room, the CO_2 level rises and the air quality is reduced. If it was not cold outside the system would tip the windows to exchange the air in the room. But to retain comfort a message appears on the screen that the air quality is decreasing and already under the specified limits. It suggests opening a window to reduce the amount of CO_2 and increase the air quality.

3.1.4.2 Diagrams

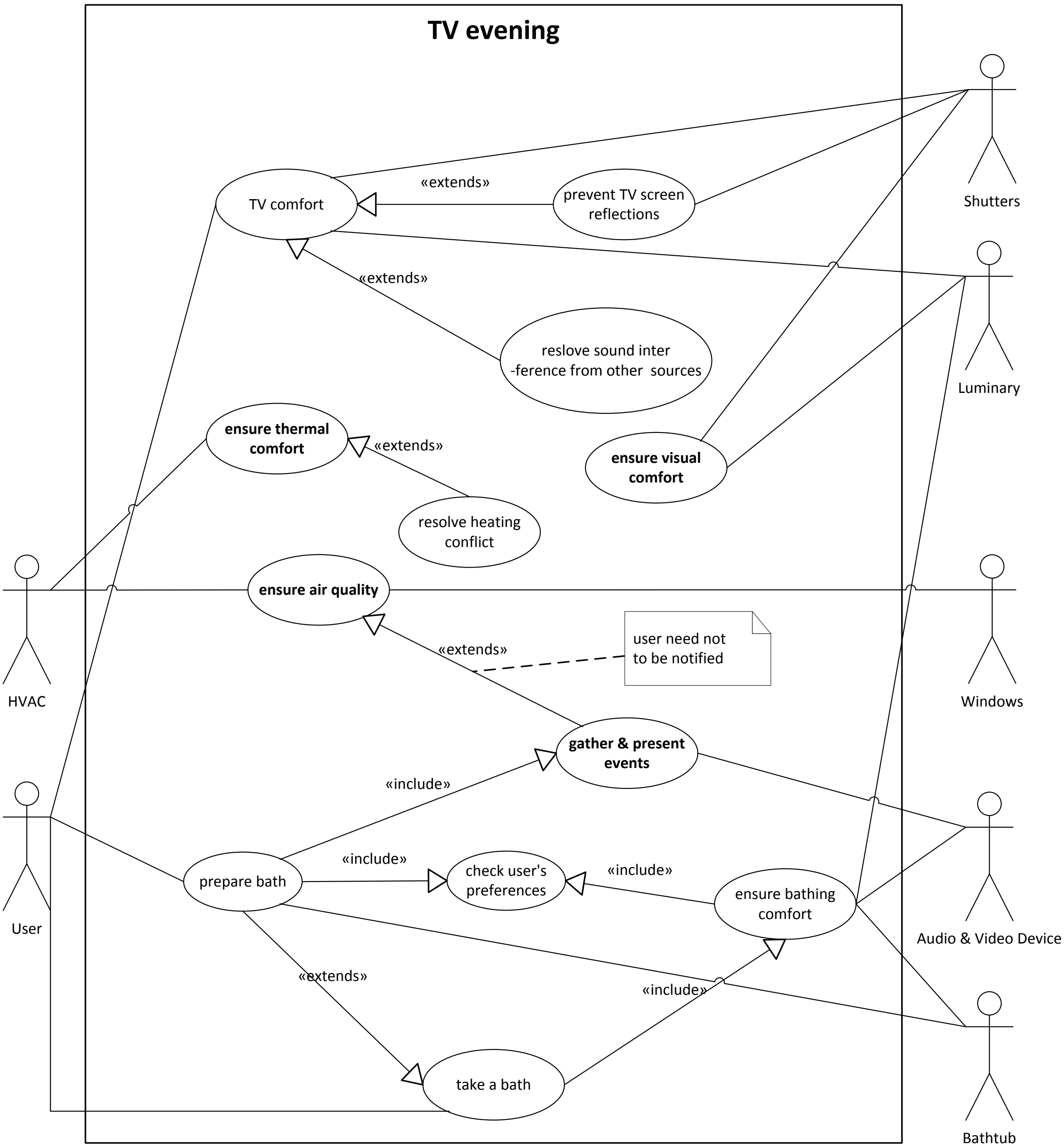

Diagram 7: TV evening Use Case Diagram

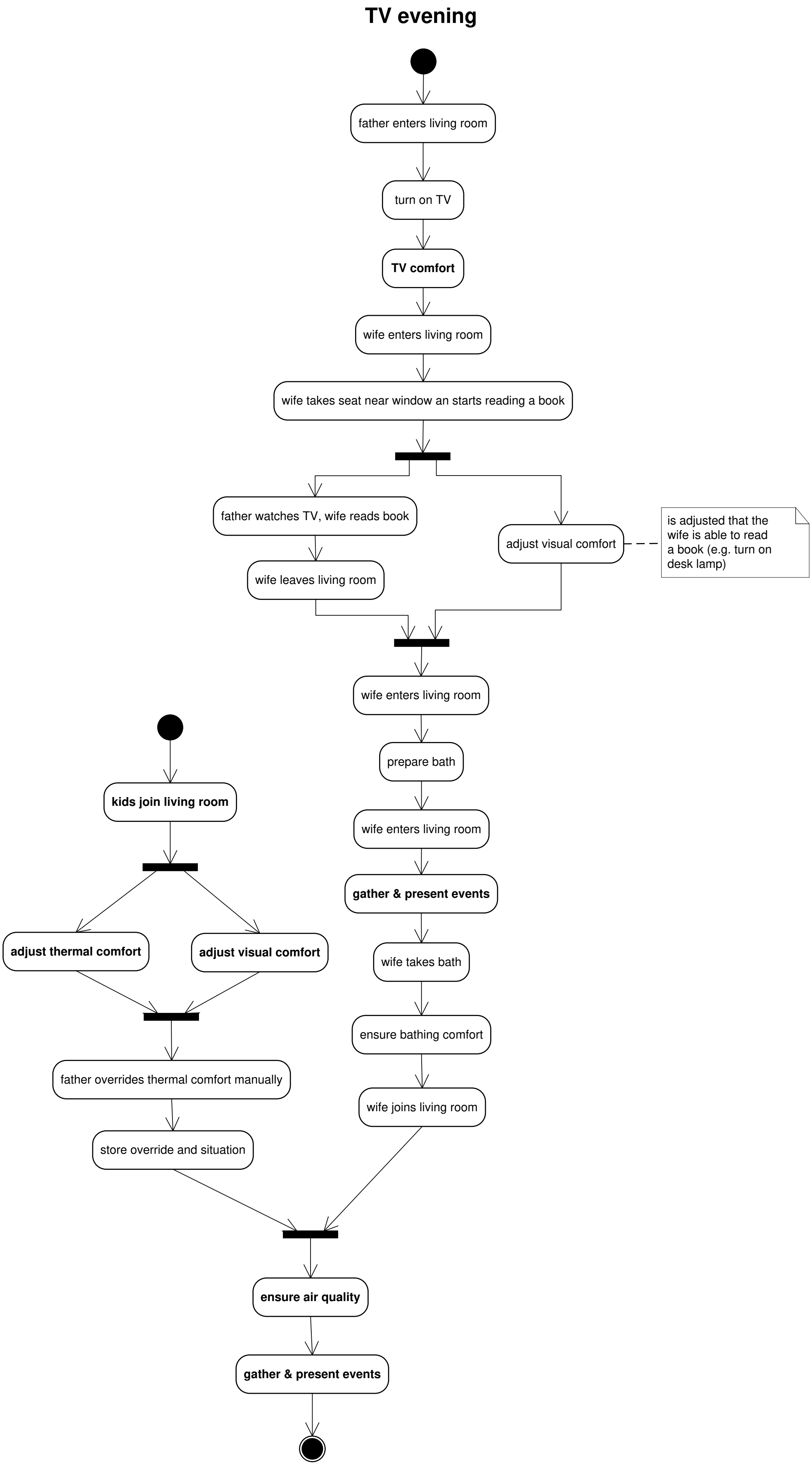

Diagram 8: TV evening Activity Diagram

3.1.4.3 List of related use cases

TV comfort

The use case TV comfort ensures a pleasant atmosphere when watching TV, especially when watching a movie. It includes several features from “*Ensure visual comfort*” and also “*Ensure Thermal Comfort*”. It ensures that there is no reflection on the screen caused by the sun or provides special lighting preferences for a pleasant atmosphere. Also it has to be assured that no other audio sources cause disturbance. The TV comfort feature can also adjust the thermal conditions of the room, because most people prefer warmer rooms if they do not move for a longer time. Due to its primary scope in comfort with no reduce in energy effort a separate description is omitted.

Take a bath

A member of the family wants to take a bath and the system fills the tub according to the preferences. It adjusts water temperature and also water height. When the bath tub is filled the mother is notified about that fact by acoustic and visual messages. During the bath also features like a special room lighting, sounds or room temperature are active. The use cases dealing with sanitary are available in chapter 3.2.9.

Ensure Thermal Comfort

In this user story, the family members are having different thermal preferences for one room. For example the father does not mind if it has about 20 degrees Celsius in the room. The kids otherwise like it much warmer, especially when watching TV so the room temperature is adjusted to 22 degrees Celsius. At the end of the story the father checks the temperature and adjusts it manually. The use case can be found in chapter 3.2.3.1.

Ensure Air Quality

After the whole family gathered in the living room and the television has been running for a long time the air quality drops quickly and the system has to ensure good comfort. Because the family has stored in its preferences that they do not like it when tipped windows cause draft, the system just informs them about the bad air quality and suggests airing the room. The complete description of the use case is available in chapter 3.2.4.1.

Gather & Present events

Again this use case is mentioned because it is an integral building block of a smart home. The system notifies the mother that the bath is filled completely when she left the bathroom. Also it notifies the family about the fact that the air quality of the room is out of its limits and suggests to tip the windows. The use case can be found in chapter 3.2.11.2.

3.2 Use Cases

The "Use Cases"-section contains a list of actors including a short description of these. This is followed by a key to the use case and activity diagrams in which common things and problem solutions are mentioned. After that, the smart home use cases that were already mentioned briefly in the user stories are explained in more detail and categorized in the different areas of home automation.

3.2.1 List of Actors

The following table shows a list of actors mentioned in this chapter's use case diagrams. The purpose is to give a clear overview because some of the actors are just a hypernym of a topic. For example, the actor "*Weather Sensors*" incorporates several features like a brightness sensors a rainfall sensors and so on.

Name	Description
User	This is a single user who is the resident of the house
Doors	All doors that are not leading to the outside of the house as well as actuators and sensors that are responsible for their control.
Windows	All windows of the house as well as actuators and sensors that are responsible for their control. (It also includes attached elements, like in one case a LED luminary)
Shutters	All shutters including the sensors and actuators that are controlling them and their single blades.
Audio & Video Device	Audio and video devices can also be called brown ware and include TV, radio, speakers, displays, HIFI, ePaper and all other electronic media that present entertainment and/or information.
Power Producers	Solar wind or other regenerative power devices as well the controlling units of them are included in this actor.
HVAC	HVAC includes all devices and appliances that deal with heating, ventilation and air conditioning.
Weather Sensors	Weather sensors cover a broad area including temperature -, brightness -, and rainfall sensors. Sensors for measuring wind speed and direction, hygrometers and so on.
Indoor Sensors	Indoor sensors measure humidity, temperature and other values that affect the room's air quality. Also brightness sensors are part of this hypernym.
Luminary	Luminary incorporates all elements that emit light including their controlling components.
White Ware Devices	White ware devices are fridges, freezers, cook tops and ovens and also washing machines and dryers.
Coffee Maker	This actor includes simple filter coffee machines and also fully automated espresso machines.
Appliances	Appliances are smaller electronic devices and may also include coffee makers in some cases.
Sink / Water Basins	This actor includes sinks and water basins as well as faucets and sensors attached to them.
Bath tub / Shower	This actor includes bath tubs or showers as well as faucets and sensors attached to them.

Table 2: List of Actors

The knowledge base[26] is not mentioned as a sole actor, because it is already a part of the system – the smart home.

[26] The knowledge base is the database for an artificial intelligence where all facts and rules (depending on the kind of artificial intelligence that is used) are stored.

3.2.2 Common things about use cases and diagrams

This short chapter serves as an overall explanation and key to the diagrams and their idiosyncrasies.

If a use case is part of (or is used by) another one, not all parameters and actors that affect the use case are listed, only the ones that differ from the primary use case. This involves use cases that are extensions for other use cases as well. Another important fact is, that there are sometimes basic versions of use cases described and later on there are extensions are variations of it mentioned, which is used to reduce complexity, overview and readability.

Although a list of actors is available it is possible that a use case differ from this list. For example, if a use case is solely realizable with a single device like a washing machine, this actor is used instead of white ware devices.

An important feature of all use cases is that they can be overridden manually by the inhabitants. This is of course very important for the user to feel comfortable in the smart home and do not be patronized or controlled by it. Although the degree of automation should be as high as possible, the user must be in control of all functions of the smart home at all times.

Another measure to get the user's approval is to allow as much customization of the system as possible. The user should be able to tailor the system's reaction to different events. For example, one can adjust if the system automatically opens the windows when the air quality is low, or if the user is just notified about that fact. Also the kind of notification, as it can be just a sound or a visual notification must be configurable.

Especially regarding HVAC and thermal comfort but also air quality regarding values for controlling the system should be avoided. Sometimes some kind of tolerance area should be implemented. In HVAC literature this is often referred to as *comfort zone*.

TRACKING OF USER'S POSITION:

Because the smart home should always be aware of the user's position this topic is important for nearly all use cases and therefore mentioned here.

One method for tracking would be that the user carries a tracking device on his body (e.g. a RFID chip[27]) and stationary motion sensors all over the house complete this version. A similar technique is used in the "Power Saver" project already described in chapter 2.5.2. For example, when a person leaves a room and nobody is in it any more, then the lights are turned off. As a person reenters the room the lights are turned on again. Naturally the lights are kept turned off if any other conditions say so (e.g. the user left the room at night and comes back in the morning when it's already bright outside).

Another method could be using a counter, which measures the number of people in rooms every time the sensors are triggered. Nevertheless this method has its disadvantages. One problem can occur if an inhabitant wants to leave the room than reconsiders and turn around as he is in the door frame. The second dilemma emerges when more than one person wants to pass through the door. In both cases the number of people counted in the room is prone to be false.

A further way to track the user's position is by the use of video cameras. To track the position of a single user in a household or to sense the presence of a person this is rather simple. It is more difficult and requires much more work from the system if the person has to be identified in a household with multiple inhabitants. The artificial intelligence has to do a lot of work when recognizing a face in real time. Currently, this may be still a problem which will be solved by more efficient algorithms and of course the increase in

27 http://en.wikipedia.org/wiki/RFID, 2010-09-01

brute processing power of computers. Of course this will be the preferred method in tracking and sensing users since the inhabitant has not to think about carrying a mobile tracking device. There is no further user interaction necessary.

As pressure sensors are already in use in some retirement homes to detect if someone fell on the floor, these sensors can also be adapted to discover the whereabouts of a person and track their paths.

3.2.3 HVAC and Control

This chapter concentrates on use cases that deal with heating, ventilation as well as air conditioning. As this is an important factor in our smart home environment to ensure the user's comfort and to reduce a lot of energy consumption this is the first section that is described.

3.2.3.1 Ensure Thermal Comfort

This use case, earliest mentioned in the first part of the second user story, takes concern of the thermal comfort of the smart home. It is one of the most complex and most detailed use cases because it includes a lot of smaller ones that are described later. Therefore, not all information that is found in the diagrams can be found in this chapter. The use case described here represents a basic version to fulfill a user's thermal preferences and a small amount of extensions follow up.

Primarily this use case is responsible for a comfortable room temperature in the house. The use case is started as soon as the inhabitant enters one. Before he enters the house the thermal conditions are relaxed to save energy. The personal preferences for the thermal condition of the rooms are loaded and compared to the current thermal condition. If the temperature is not in the user's comfort zone the room (house) temperature is adjusted. For that reason, the outdoor temperature is measured and compared to the indoor temperature first. If the room needs to be cooled and the outside temperature is lower the windows are tipped or even completely opened. The temperature difference needs to be taken into account to not cause any uncomfortable draft. Another important factor is rainfall. The windows cannot be opened completely if it is raining outside and in extreme cases they cannot even be tipped. Of course if the room is heated up too much the air condition must be activated to reach a convenient temperature. This may also happen if the outdoor temperature is higher than the indoor temperature. Additionally, the shutters can be lowered to prevent the room from heating up from the sun insulation. Also the windows can be tinged with a switchable glazing which has a similar effect than shutters.

The opposite case, if the room needs to be heated is easier. First of all, the system checks if shutters are down or the windows are tinged and if the room can be heated just by letting the sun insulation heat it up. Most of the time, this will not be possible so the heating has to be adjusted to reach a comfortable temperature.

Over all these occurrences the thermal inertia of the room are considered which can lead to lower heating or cooling efforts.

Use Case Summary:

Name	Ensure thermal comfort
Goal	• Provide well tempered rooms for the residents.
Summary	Ensure perfect thermal conditions in rooms where the inhabitant is. First of all, low energy measures like adjusting shutters or opening windows are used. If these are not effective then heating or air conditioning is activated to reach the desired temperature.
Actors and Stakeholders	• HVAC • Windows • Shutters • Indoor Sensors • Weather Sensors • (User (in house or not))
Parameters	• User preferences • Indoor temperature • Outdoor temperature • Sun insulation • Rainfall • Thermal inertia of room • Window status (open/closed) • Window tinge • Shutter status
Pre condition	• Setback temperature (relaxed thermal conditions for rooms)
Post condition	• Thermal condition matching user's preferences

Adjust HVAC strategy to current weather changes

Another aspect that is mentioned is the adaption to the current weather situation to react earlier if a change in room temperature can be expected. In the described case in the second user story it was a hot summer day and it started raining. The system recognizes that and while checking the current outdoor temperature also knows that the temperature will drop more the longer it is raining. So the air conditioning is shut down and as the outdoor temperature falls below the indoor temperature the windows are tipped. This would also increase the room's air humidity, so the use case *"ensure air quality"* is also affected. If the inhabitants are at home and it stopped raining the windows can be opened as a whole to speed up the room's cooling. Also early lowering of shutters or tinging of windows when high sun insulation is recognized can save energy. This thought can be adjusted to several other weather situations to help reducing HVAC energy consumption. The system can also reduce heating when the sun comes out after a long cloudy time, at least in rooms where the sun shines directly into the windows. The building orientation is an important factor that should not be forgotten. Next to the sun, that does not heat up rooms that are averted from its insulation, also wind that hits windows is cooling the rooms as well as rainfall in combination with wind can affect the HVAC efforts that have to be spent.

Therefore the smart home stores and analyzes historical weather data of the house, which is already used in a lot of commercial and office buildings. Until now most BMS use previous day's weather records to set optimal heating or cooling for the actual day. It is obvious that this method can lead to a high fault quota.

As a result of this, newer versions of BMS fetch the weather prediction for the next day(s) from meteorological institutes over the Internet (often every few hours) and the smart home is fed with this prediction data to compute set points for HVAC. So the building can be pre-tempered for the next day which leads to significant savings. A detailed description can be found in chapter 3.2.3.2 -"*Adjust HVAC strategy to forecasted weather changes*".

Use Case Summary:

Name	**Adjust HVAC strategy to current weather changes**
Goal	• Reduce energy effort
Summary	The HVAC system adapts to current weather changes that occur. E.g. it reduces the cooling when it rains
Actors and Stakeholders	• Indoor sensors • Weather sensors • Windows • HVAC • Shutters
Parameters	• Current weather data • Room temperature • Shutter status (raised/lowered) • Window tinge status
Pre condition	-
Post condition	• Lower heating/cooling effort

Save user's home coming times for heating/cooling

As a method to increase efficiency of keeping the house at its optimal temperature, the smart home stores the user's arrival times like it is described in the second user story "*Coming Home*". This part can be seen as an upgrade to a time scheduled operation of HVAC devices like it is already common in nearly all households. But instead of setting the time manually when the HVAC is activated and shut down, the smart home decides by the user's daily presence when it's appropriate to do that.

This can be achieved by observing several parameters. The system checks the user's schedule for this day and if he has any appointments after work. If not, the system assumes that he will be home as usual. If the user has an appointment, the system takes that into account and starts tempering the room later. As the system knows from historical house data how long it takes the rooms to get from the actual temperature to the user's preferred temperature (thermal inertia), it can choose the perfect time to start heating or cooling.

Use Case Summary:

Name	Save user's home coming times for heating/cooling
Goal	• Provide well tempered rooms for the resident when he is entering the house.
Summary	The weekly schedule of the users and their times for leaving and entering the house are stored. Due to the current weather situation an appropriate time before the first user enters the house heating respectively cooling is activated to achieve the user's desired temperature.
Actors and Stakeholders	• User • HVAC • Windows • Shutters
Parameters	• Time when user comes home
Pre condition	• Setback temperature (relaxed thermal conditions for rooms)
Post condition	• Thermal condition matching user's preferences

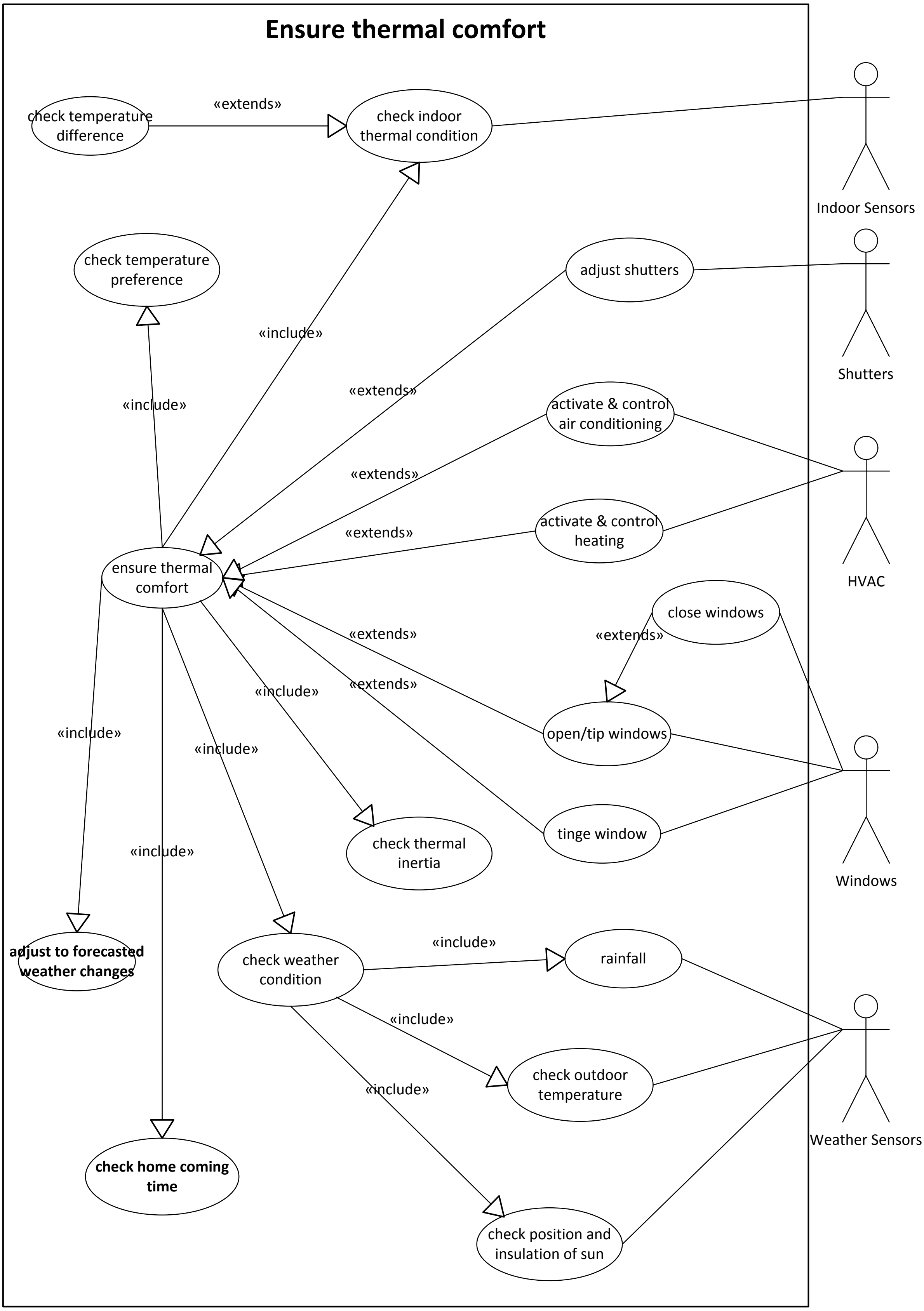

Diagram 9: Ensure Thermal Comfort Use Case Diagram

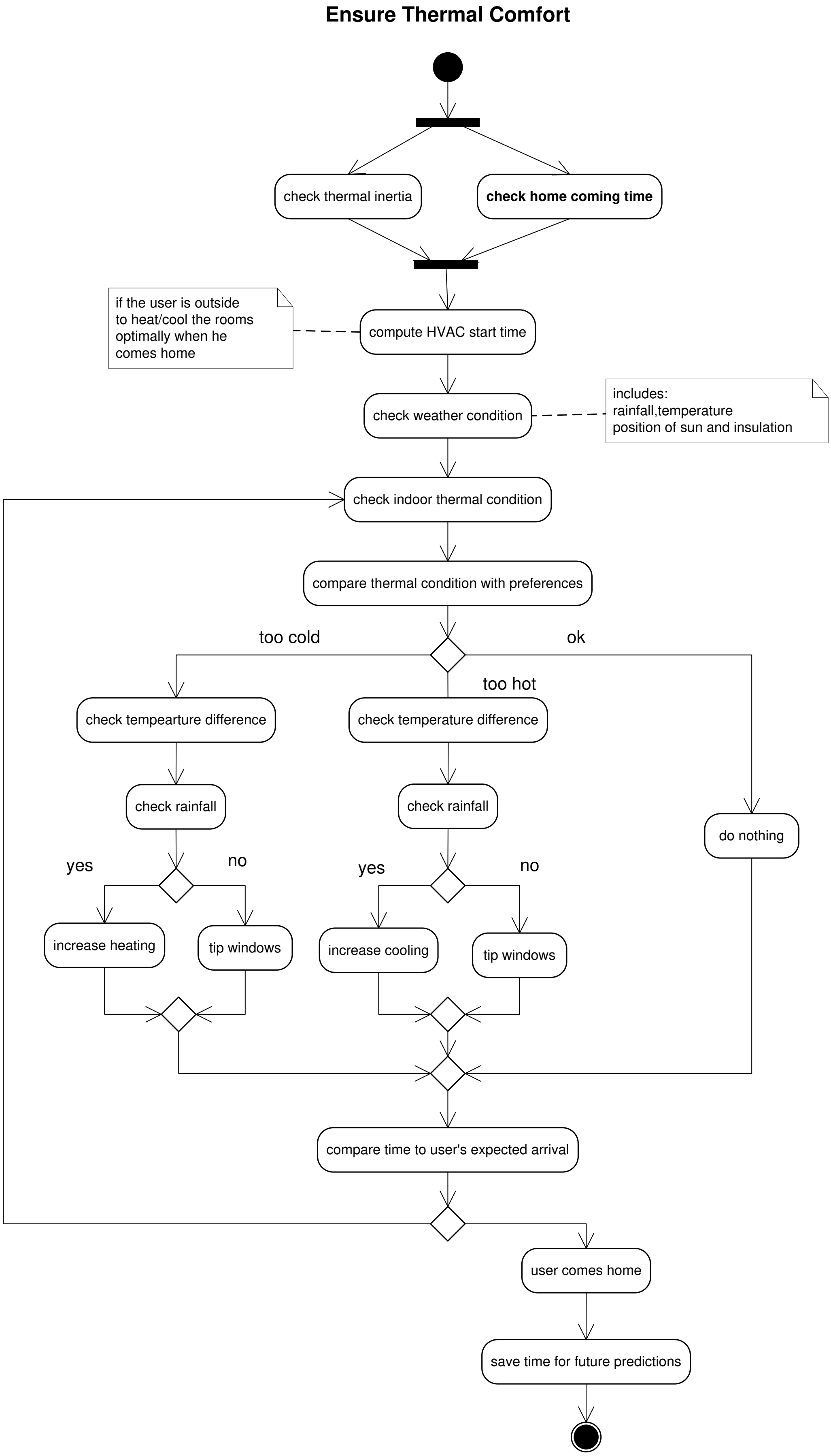

Diagram 10: Ensure Thermal Comfort Activity Diagram

3.2.3.2 Adjust HVAC strategy according to weather forecast

Because older BMS produce a high fault quota, as they were just taking weather data from previous days into account [FISC2009], newer versions of BMS fetch the weather prediction for the next day(s) from meteorological institutes over the Internet (often every few hours) and the smart home is fed with this prediction data to compute set points for the HVAC system. So the building can be pre-heated respectively pre-cooled for the next day which leads to significant savings. Especially in cooling cases the system can decide to start cooling when energy is cheaper (at night). This method primarily makes use of a building's thermal inertia. This can be achieved by so called thermo active building components for example, that are already built-in in many larger office buildings. However, they would also be a big enhancement in energy saving efforts of domestic houses or any other residential buildings. Thermo active building components are tubes filled with water that are built into the concrete of a house. By regulating the water temperature, the house's thermal condition can be regulated optimally with low energy effort. With the use of weather forecast data the energy needed for HVAC can be significantly reduced. For example, if the forecast says that it will get cooler the next day, the air condition need not to be turned on because the smart home knows that the rooms will not heat up that much during the day. Also heating can be decreased earlier if the weather data assumes that it will get warmer in heating periods.

Use Case Summary:

Name	**Adjust HVAC strategy to forecasted weather changes**
Goal	• Reduce energy effort
Summary	The weather forecast for the next day is retrieved (over the Internet) several times a day. If the weather is getting hotter, than the concrete core is cooled. If the weather is getting cold and the building's heating has to be activated, then the concrete core is warmed to keep the rooms at the optimal temperature. So the rooms are preheated or precooled according to the weather. If the temperate cannot be achieved by this means, than the HVAC is activated.
Actors and Stakeholders	• Weather forecast • HVAC
Parameters	• Weather forecast • Indoor temperature • Thermal inertia (historical data analyzed) • Outdoor temperature
Pre condition	• Temperature out of comfort zone
Post condition	• Lower energy efforts when applied • Thermal comfort is reached

3.2.3.3 Store wandering of shadows over building

The thought behind this use case is to take into account on which time of the day a room respectively its windows lie under a shadow. If that happens the cooling for this room can be reduced due to the missing sun insulation. In urban areas this shadows often origin from large buildings or nearby houses, in rural areas also trees can be the source.

To achieve this, a so called shadow cast diagram has to be charted for the house that stores which windows are covered by shadows during which time of day and season. Now the smart home can reduce the cooling already before that happens because less sun insulation means less room heat up. On the other hand, the room might also need more heating in winter. This use case is already implemented in several modern office buildings but may also be an option for single houses and residential buildings.

Use Case Summary:

Name	**Store wandering of shadows over building**
Goal	• Reduce energy effort
Summary	The shadows casted on the house are stored. When a shadow hits a room and it's windows, it needs less cooling during summer and more heating in heating periods in this time frame. This information can be incorporated in the HVAC control strategies
Actors and Stakeholders	• HVAC
Parameters	• Shadow cast diagram • Indoor temperature
Pre condition	-
Post condition	-

3.2.3.4 Adjust HVAC to number of people in rooms

This use case would be suitable for rooms occupied by more than one person at the same time and for longer time periods. In residential buildings this could be the kitchen or the living room. The more people are in a single room, the more the room is heated by their own body warmth. This means less heating in winter but again more cooling in summer.

It is not taken into account that the persons may have different personal preferences regarding the room's thermal condition. If a person enters a room the heating is slightly reduced due to the estimated heat emission of this person. If another person enters the room the heating is reduced further. If a person leaves the room the heating is increased again. Of course it is the other way round when the room needs cooling; the more persons are situated in this room the more cooling is necessary to reach the desired temperature.

Another extension would be to take the person's clothing as well as actual activity into account. The clothing of a person is measured by clothing units[28] and is a factor for the thermal isolation. The more and thicker cloth a person is wearing the less warm a room needs to be. The system can identify rooms where a person is wearing more clothes than others (e.g vestibule, cellar) and reduces the temperature optimum of this room. Also rooms that are used for certain activities can have different optimal temperature values. For example hobby rooms where inhabitants train on spinning wheels or do dumbbell workout are easily heated up in a short time. So the heating can be deactivated earlier or on the other hand the air condition has to be increased to reach the optimal thermal level.

[28] 1 clo (clothing unit) = 0,155 m^2 K/W

Use Case Summary:

Name	**Adjust heating/cooling to number of people in rooms**
Goal	• Reduce heating efforts • Ensure stable temperature level
Summary	A person enters a room. The system reduces heating in winter. The system increases cooling in summer. When another person enters the room the HVAC is adjusted one more time. If a person leaves the room the HVAC is adjusted another time.
Actors and Stakeholders	• User • HVAC • Windows (can be used to regulate room temperature) • Indoor sensors • Weather sensors
Parameters	• Indoor temperature • Outdoor temperature • Thermal inertia of room • Heat emission per person • User activity • User cloth
Pre condition	• Room temperature is in predefined boundaries
Post condition	• HVAC control is achieved with respect to number of people in rooms

3.2.4 Comfort

This chapter focuses primarily on the peoples comfort before taking energy reduction into account. To assure the inhabitant's convenience even an increase in energy reduction is allowed (to an admissible limit). But to gain an increase in comfort does not mean just to have a higher energy effort. Some use cases even decrease the energy needed as a convenient side effect.

3.2.4.1 Ensure Air Quality

An important feature in our smart home is that the system ensures a perfect air quality. Though by its definition room air quality cannot be measured because it depends on the subjective sense of the inhabitants, it is clearly a significant factor in establishing smart homes. In the smart home, nobody needs to take care of the air quality by opening windows manually. The system takes on this task to ensure a perfect air quality for its inhabitants the whole time. The user must not fear a loss of control though. Certainly all windows can still be opened manually without restrictions. Also a notification system, which encourages the user to open the windows, can be implemented instead of automated actions. This feature is not just improving the inhabitant's comfort it is also a noticeable improvement in energy reduction.

Of course, the most important value ensuring a human's comfort in a room is the temperature. This is not described in this chapter. Instead, there is a use case taking concern of the thermal comfort in Chapter 3.2.3.1.

Automated Airing by CO_2 level

Studies from [HORN2006] are evaluating the distinction of different ventilation strategies. In their scenario the most important factor in air quality convenience is the carbon dioxide level which should be measured in a position that is not directly affected by fresh air. The limit value for good air quality is 1000 ppm CO_2. The frequency of opening the windows is controlled by that value. Their test topics are controlled shock airing and controlled split airing.

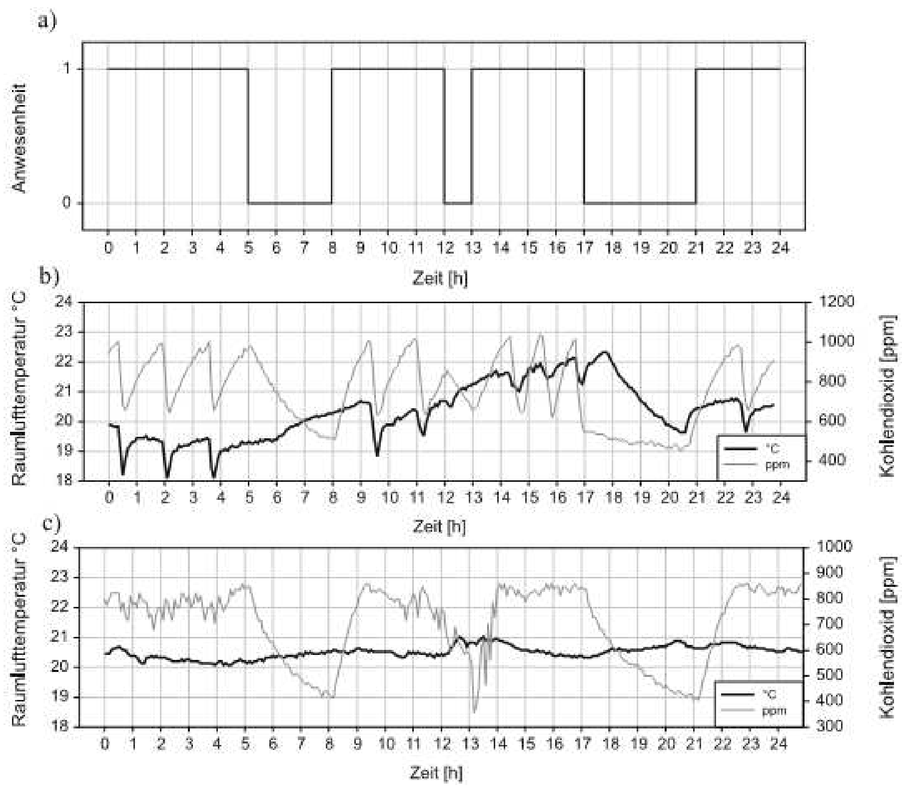

Figure 11: Progression of air temperature and CO2 concentration for a presence pattern (a) with regulated shock ventilation (b) and regulated split ventilation (c) [HORN2006

Figure 11 shows the different progression exemplary for a presence pattern (a) with regulated shock ventilation (b) and regulated split ventilation (c). Both ventilation strategies should not exceed the predefined value of good air quality (1000 ppm CO_2 at maximum). The two-point strategy with shock ventilation is regulated to a limit of 900 ppm CO_2 to tip windows to its maximum and the second limit is 700 ppm CO_2 to close windows again. It is clearly visible that shock ventilation leads to a high fluctuation of temperature in the center of the room, which even drops to 18° Celsius. This is sensed as draft and uncomfortable for the inhabitants. During absence times, room temperature rises even over 22°C.

With regulated split ventilation, the carbon dioxide level tended to stay around 850 ppm and temperature fluctuation is far smaller and dithers around 20.5° Celsius. This is much more comfortable for all inhabitants and risk of draft is reduced. This study shows clearly that automated split ventilation is more suitable to contribute to comfortable room climate.

But the user's comfort is not the only thing that can be improved; therefore the study also compared the diverse energy efforts. Table 3 shows the calculated energy consumption of three different ventilation strategies. The preferred strategy for automated ventilation is constant split airing due to its big advantages in people's comfort.

	Constant ventilation	2-point split ventilation	Regulated split ventilation
Absolute	3367 kWh	1259 kWh	1239 kWh
Relative	231%	100%	98%

Table 3: calculated energy consumption of different ventilation strategies [HORN2006]

Use Case Summary:

Name	**Automated airing by CO_2-level**
Goal	• Ensure perfect air quality (regarding CO_2-level)
Summary	The system is alarmed by a CO_2-sensor that the limit is reached. The windows in the room are tipped for fresh air. If a user is situated next to a window it is just slightly tipped.
Actors and Stakeholders	• User • HVAC • Windows
Parameters	• Indoor CO_2-level • Window status (open/closed) • User location • Outdoor temperature • Indoor temperature • Heating effort for opening window
Pre Condition	• CO_2-level too high
Post Condition	• CO_2-level in defined limits

Automated airing by air humidity (ensure air humidity)

The implementation of such an automated airing can include several other parameters besides CO_2. Most of them seem only to fulfill comfort issues but they can also lead to a reduction in energy efforts. An example of such a parameter is the room's air humidity. Especially in winter when the houses are heated rooms suffer from low air humidity. According to medical advisors, when relative air humidity falls below a value of 20 percent, humans can experience dryness and therefore irritation of eyes. As a matter of fact, for humans feeling of heat is higher in rooms with higher air humidity and so rooms need less heating. The opposite situation arises during hotter periods like summer month. Many homes have a constant high air humidity which is harmful to wooden movable and fitments and the air feels heavy. According to DIN 13779[29], optimal humidity boundaries are between 30 percent and 50 percent.

Use Case Summary:

Name	Automated Airing by air humidity (ensure air humidity)
Goal	• Ensure perfect air quality (regarding air humidity)
Summary	The system is alarmed by a hygrometer that the limits are reached. To reach the desired air humidity either the window is tipped or an air humidifier/dehumidifier is activated. If a user is situated next to a window it is just slightly tipped.
Actors and Stakeholders	• User • HVAC • Window • Air humidifier/air dehumidifier
Parameters	• Indoor air humidity • Outdoor air humidity • User location • Outdoor temperature • Indoor temperature
Pre Condition	• Indoor air humidity not in comfort zone
Post Condition	• Indoor air humidity in comfort zone

Automated airing by ground plan

The last use case mentioned in this User Story is the automated airing by ground plan. The ground plan of the house or the flat is stored in the system's knowledge base to improve the automated airing. Especially in winter, when a correct airing strategy is crucial for not letting the rooms getting too cold, consideration of the house's ground plan can lead to an energy reduction.

In the first user story – Single Person Household - Morning Routine – the system waited with a complete airing of the house until the inhabitant has left, since the user could be disturbed of cold draft in certain rooms. As the house is cleared, the system checks the ground plan and opens specific in-house doors and also the windows to achieve a massive air exchange in a minimum time frame. In winter, the rooms are not

[29] "DIN EN 13779:2007 - Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems", Beuth Verlag GmbH, Berlin, 2007

cooled down as much and thus heating need not be increased that much. In summer, less warm air from outside is flowing into the room and cooling efforts are reduced.

However, it should not be disregarded that this method has its disadvantages. It is a matter of fact that draft can whirl papers, mail or magazines around and even flower pots are not always safe from it. The automated opening of windows and doors must also hold them in position so that they cannot slam and may be damaged.

Use Case Summary:

Name	**Automated Airing by ground plan**
Goal	• Save energy by reducing time for complete air exchange
Summary	The system stores the perfect ventilation strategy for the house by using the stored ground plan. The system checks if no user is in the house and then opens all doors and all the windows to achieve a perfect air exchange in a minimum timeframe.
Actors and Stakeholders	• Windows • Doors (indoor) • User • Weather Sensors • Indoor Sensors
Parameters	• Wind speed • Outdoor temperature • Indoor temperature
Pre Condition	-
Post Condition	• The room's air is exchanged • Reduced time for air exchange • (Less energy effort)

Next to all these parameters aerial pollutants from furniture, polishers, fine dust particles and so on can reduce a room's air quality. Especially in the last years stand alone devices emerged into the domestic area taking concern of this problem. They suck air into them clearing it by active carbon or HEPA filters leading to a higher comfort for inhabitants. Of course, this feature is often integrated in the house's ventilation system.

A problem that often occurs in hot summer months is near-ground ozone which is responsible for respiratory diseases at a higher concentration. When the system is airing the house (especially when a complete air exchange is aspired) this should be considered and maybe the duration of airing should be reduced in favor of a better health and comfort.

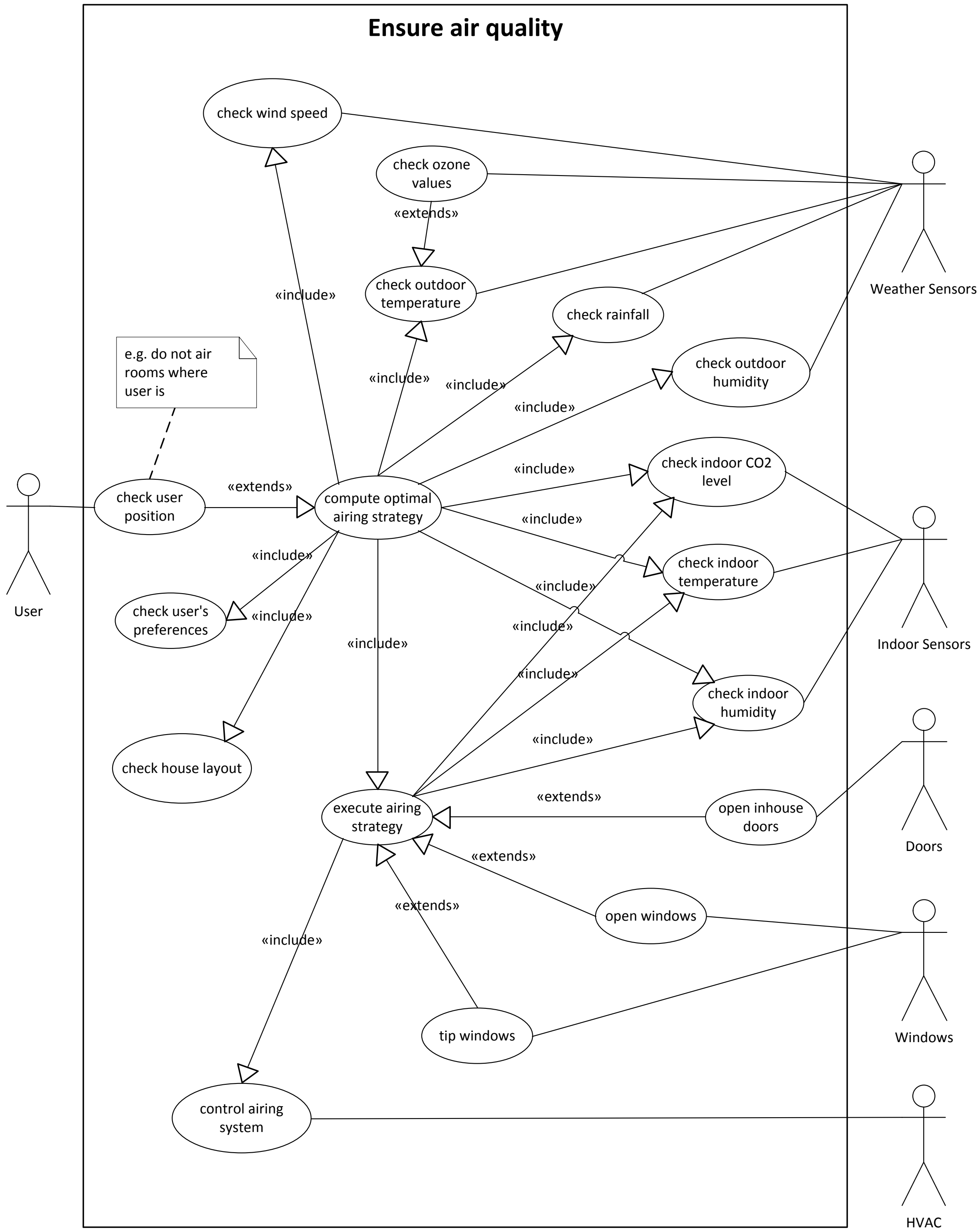

Diagram 11: Ensure Air Quality Use Case Diagram

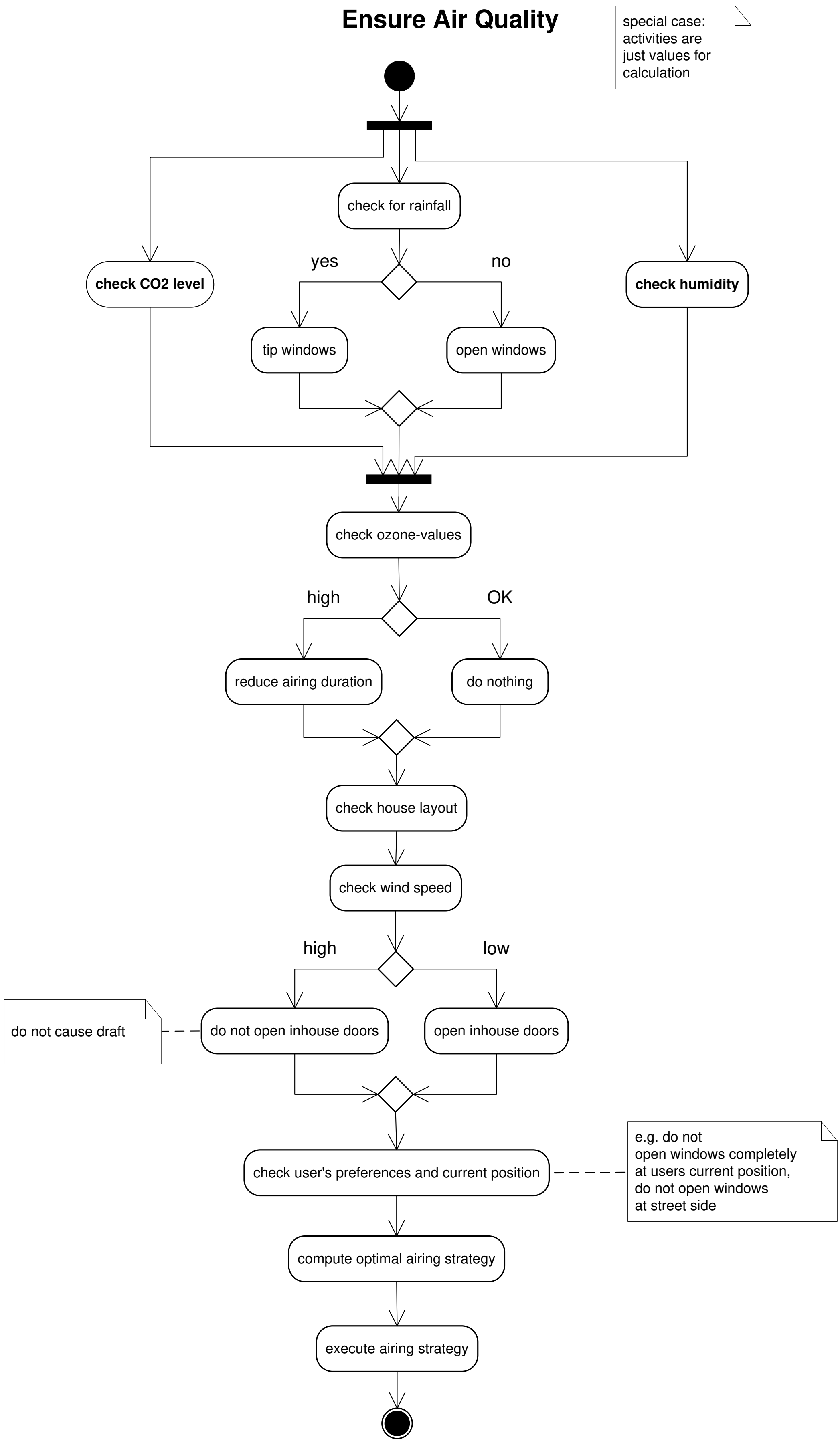

Diagram 12: Ensure Air Quality Activity Diagram

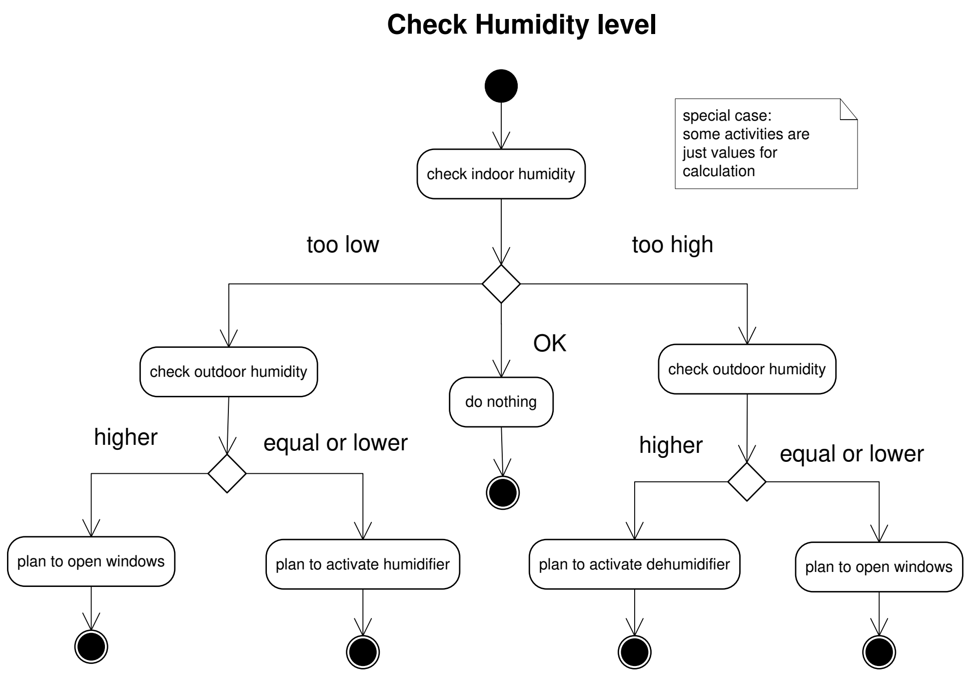

Diagram 13: Check Humidity Level Activity Diagram

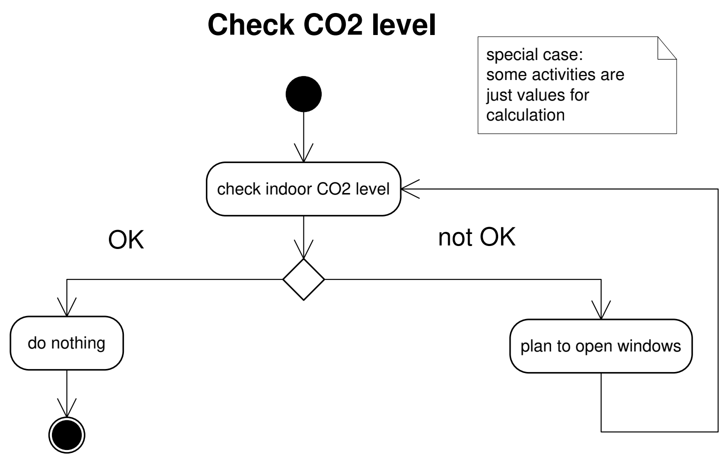

Diagram 14: Check CO_2 level Activity Diagram

3.2.4.2 Leave House

This use case involves several functions of the smart home in several categories including HVAC, lighting or security and includes four other use cases. It is triggered when the user leaves the house. First the system stores the leaving time to improve the algorithm for the user's absence times. In the first user story, the inhabitant is on his way to his working place and the system knows that he probably will be away for at least 8 hours. He will not be coming back until evening 7 o'clock p.m. Also his schedule is checked if there are any appointments besides work.

Besides that all electronic devices and appliances are shut down (3.2.7.3) or even separated from the power net. Also luminaries are automatically turned off if that was not already done (3.2.6.3). The system checks if any windows or doors were left open and closes them automatically to improve security (3.2.5.1). To save water from dripping faucets the main water conduit is closed (3.2.9.2). The last involved feature which was already mentioned earlier is *Ensure Air Quality (3.2.4.1)*. Especially after all inhabitants left the house the system can do a complete air exchange without disturbing anyone. After the airing, all windows are closed again.

The scenario starts as soon as the user leaves the house and locks the door.

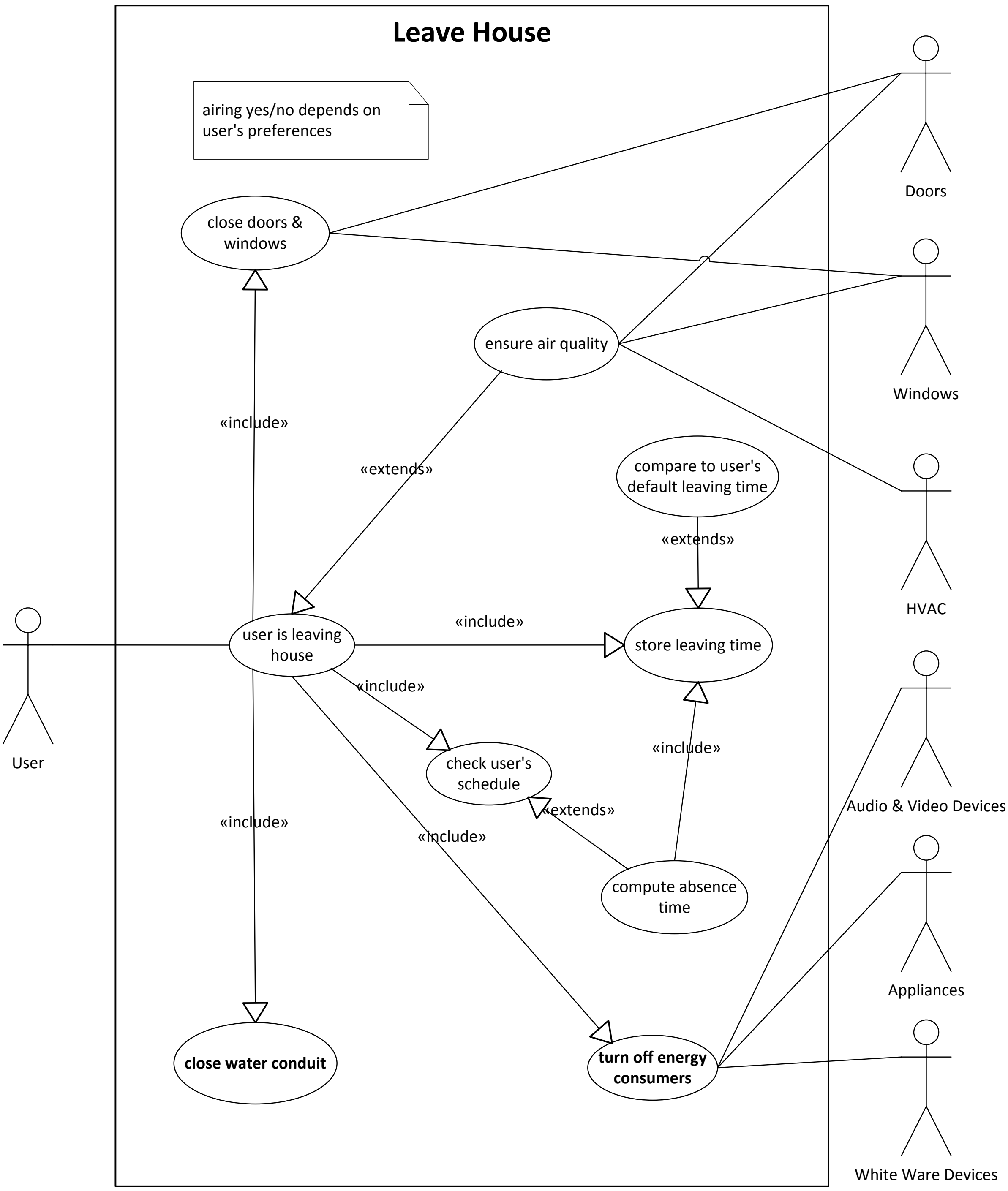

Diagram 15: Leave House Use Case Diagram

Diagram 16: Leave House Activity Diagram

3.2.4.3 Inform user when room needs airing

This use case can either encourage the inhabitant to manually air rooms correctly or is an option if the inhabitant does not want to automatically air the rooms for some reason to keep in control of what is happening in the house. The system checks the room's air quality (for a detailed description look 3.2.4.1) and if it is out of limits, it notifies the user that the windows should be tipped. This could either be an acoustic message or a message on a display or just a LED light attached to the window frame turning red or starts blinking to be more noticeable. As soon as the air quality is in its boundaries again, the system notifies the user about that, so he can close the windows again.

A further extension to this system is to not just show the correct airing period on the windows but also give the user recommendations which windows can be opened additionally. Therefore a sketch of the house's ground plan is showed on display near to the user position or showed if the user presses a button on one of the multifunctional displays that are positioned in nearly every room in the house. On the ground plan the windows that should be opened for optimal airing are marked. A feature that will help the user to understand the suggestions would be to show an animated illustration of the air flow that is achieved by opening all marked windows.

Use Case Summary:

Name	**Show user when room needs airing**
Goal	• Ensure air quality • (Train user to air correctly)
Summary	The system recognizes that a room's air quality (CO_2) is low. A led-light attached on a window begins to light / blink to indicate the user that it should be opened. When the air quality reached a limit the light begins to flash again to show the user that it should be closed. The system can also display a ground plan on a screen to demonstrate which windows should be opened.
Actors and Stakeholders	• Windows • User • Indoor Sensors • Audio & Video Device (Display)
Parameters	• User position • CO2 level • Ground plan
Pre condition	• Air quality is out of its limits
Post condition	• Air quality is perfect again

3.2.5 Windows & Doors

This chapter deals with use cases that deal with windows and doors and do not completely fit into the section of HVAC or comfort. The primary goal of the presented use cases is to reduce the energy effort by correcting some events that are caused by the oblivion of the inhabitants.

3.2.5.1 Close ore notify user of open windows/doors before leaving / going to sleep

This feature pursuits two goals: First increasing security and second reducing energy efforts for heating or cooling as well. But also the ecological awareness of the smart home's inhabitants will be trained.

If a user is located near the coat rack for a longer period of time (as it can be seen in user story number three), because he wants to leave the house, the system notifies him of all doors and windows that are still open. Another possibility for the system to know that the user will leave the house soon is, if he made an appointment and entered it into his personal schedule. As he takes on his clothes and shoes the user is notified about any open window or door. Although the system would automatically close them as soon as the user leaves the house, he can choose on receiving a notification and close them on his own.

This feature is always triggered a short time before somebody would leave the house and there is nobody left in the building.

Use Case Summary:

Name	Automated closing of forgotten windows (doors)
Goal	• Save energy by closing windows that were left open • Increase security
Summary	The system recognizes that all users have left the house or are at sleep. It checks which windows are left open and closes them as long as there is not any air exchange or other HVAC-program active that requires them to be left open.
Actors and Stakeholders	• Windows • Doors • User
Parameters	• User position (activity) • Window status (open/closed) • Door status (open/closed)
Pre condition	• Window/door is open
Post condition	• Window/door is closed

Use Case Summary:

Name	Notify user of open windows (doors) before leaving / going to sleep
Goal	• Reduce energy usage • Increase security • (Increase user's awareness)
Summary	The user is at the coat rack near the house door. The system checks the user's schedule if there is any appointment causing him to leave the house. If the schedule says yes, the system notifies the user to close windows, which were left open. If the schedule is indefinite and the user reaches the house door, the system notifies the user to close the open windows.
Actors and Stakeholders	• Windows • Doors • User
Parameters	• User position (activity) • User schedule • Window status (open/closed) • Door status (open/closed)
Pre condition	• Window/door is open
Post condition	• User is notified about open door/window

3.2.5.2 Shutting down HVAC when a window is open

This feature is already used in several commercial and office buildings, ensuring not to waste energy when the users manually open windows. It is also utilized when the system takes action to ensure air quality.

Because the windows (and of course also the house doors) are already equipped with contact sensors, the smart home can easily recognize when a window is not closed. If the HVAC is currently activated and a window is opened, the heating and air conditioning is deactivated for this room. As soon as the window is closed again, the HVAC is turned on.

Use Case Summary:

Name	**Shutting down HVAC when a window is open**
Goal	• Reduce heating/cooling effort
Summary	When a window is opened manually by a user or automatically according to the airing strategy the heating or air condition for this room is shut down. When the windows are closed again the heating or air condition is activated again.
Actors and Stakeholders	• Windows • HVAC
Parameters	• Window status (open/closed) • HVAC status (on/off)
Pre Condition	-
Post Condition	-

3.2.5.3 Inform user of optimal airing

If a window is opened manually by the user the system checks constantly if the room is too much warmed up or cooled and if that increases the energy efforts. If that is the fact and the window is open longer than a specific time (for example 10 minutes) the system informs the user. This can either be acoustic message over speakers or by a status message on a display near the user or even just a LED light integrated into the window frame.

3.2.6 Lighting & Shading

The following chapter contains use cases that control luminary as well as shading equipment and therefore the brightness conditions in rooms. Some of the uses cases concentrate on reducing energy efforts but there are also various that increase the user's comfort either as a side effect or having this as the primary goal. A household's lighting has a share in energy consumption that should not be scoffed at.

3.2.6.1 Ensure Visual Comfort

"Ensure Visual Comfort" is one of the most complex use cases and using a lot of smaller use cases – that are mentioned and described separately – to achieve their objectives. Besides the control of luminary also shutters and the tinge of windows are controlled. The goal of this use case is primary to adjust the room brightness to the user's preference so that he feels comfortable. But as a secondary goal also a reduction in energy efforts is targeted. This shall be achieved by using as much natural light as possible and only turn on the luminary if it the desired brightness cannot be achieved without it.

The first task of the smart home is to check when a user enters a room, if the room brightness matches the user's preferences. There are several scenarios that can occur to adjust the actual illumination level. Measures to achieve the desired illumination level with less artificial lighting are described later in this chapter.

The basic assumption is that there is no luminary turned on and the room's shutters are raised. If the brightness in the room is too low, the luminary is turned on and increased till the brightness level is sufficient, which is the simplest case. If the brightness level is too low and the shutters are lowered, the system first pans the blades as long as the user's preferences are not matched. If that is not enough, then the shutters are raised and after that the luminary is activated.

If it is too bright in the room and there is no luminary turned on and the shutters are open, then there are two possibilities for the system which are strongly dependent on the user's preferences. Either the system can tinge the windows or lower the shutters as long as the room brightness is at a comfortable level. Regarding the visual comfort there is not much difference between tinged windows and lowered shutters. The advantages of shutters are that they keep more sun insulation and therefore heat outside but tinged windows may increase the comfort because you still have a nice view instead of looking at panned blades.

Use Case Summary:

Name	**Ensure Visual Comfort**
Goal	• Provide desired brightness conditions in actual room • (Save energy)
Summary	When a user enters a room the smart home checks the current room brightness and the user's preferred brightness. If that does not match, then the brightness is adjusted by using shutters, window tinging or luminary.
Actors and Stakeholders	• Windows • Shutters • Luminary
Parameters	• Indoor brightness • Outdoor brightness • User preferences

	• User location
Pre Condition	• Brightness level out of bounds
Post Condition	• Room brightness meets users preferences

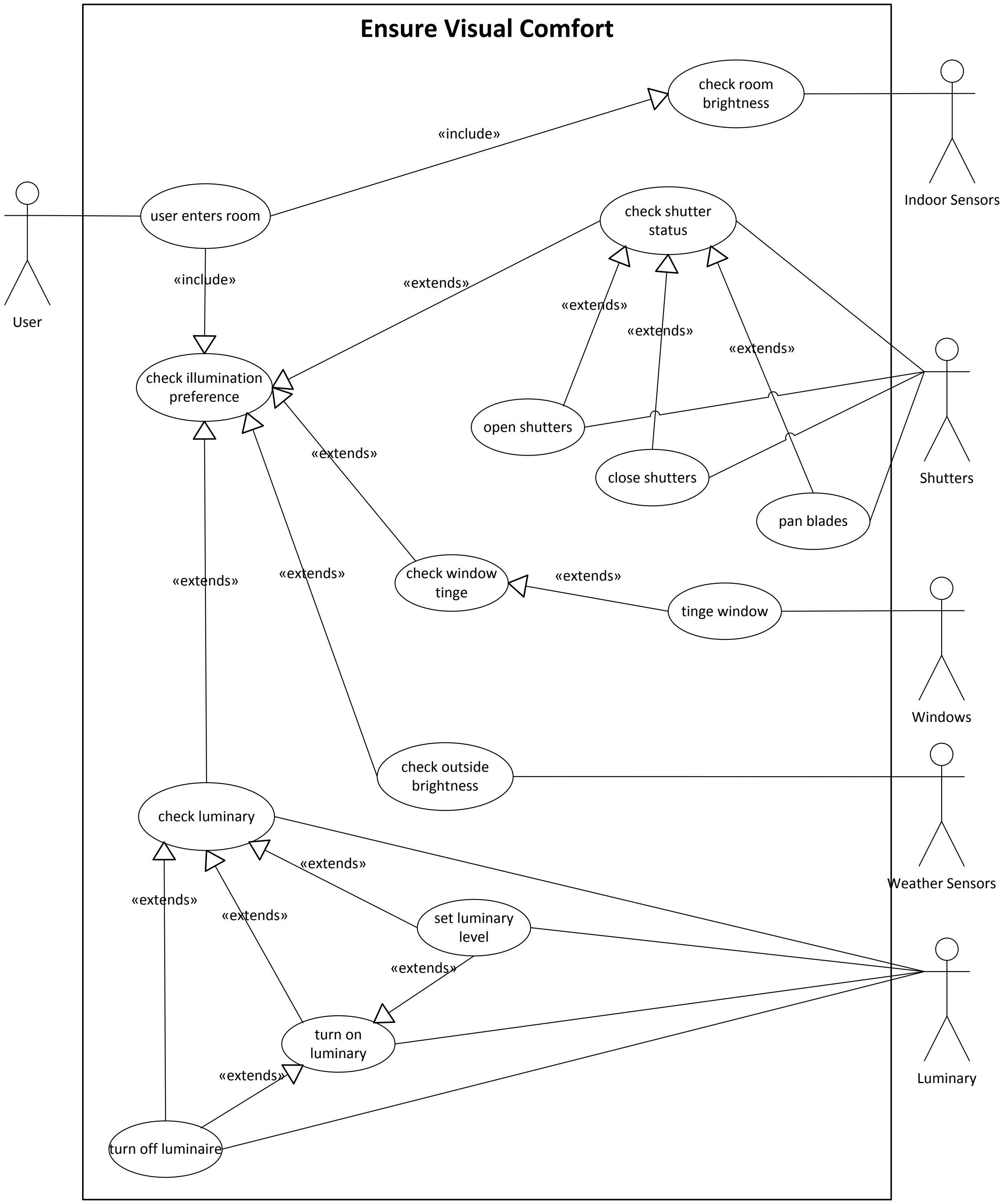

Diagram 17: Ensure Visual Comfort Use Case Diagram

Ensure Visual Comfort

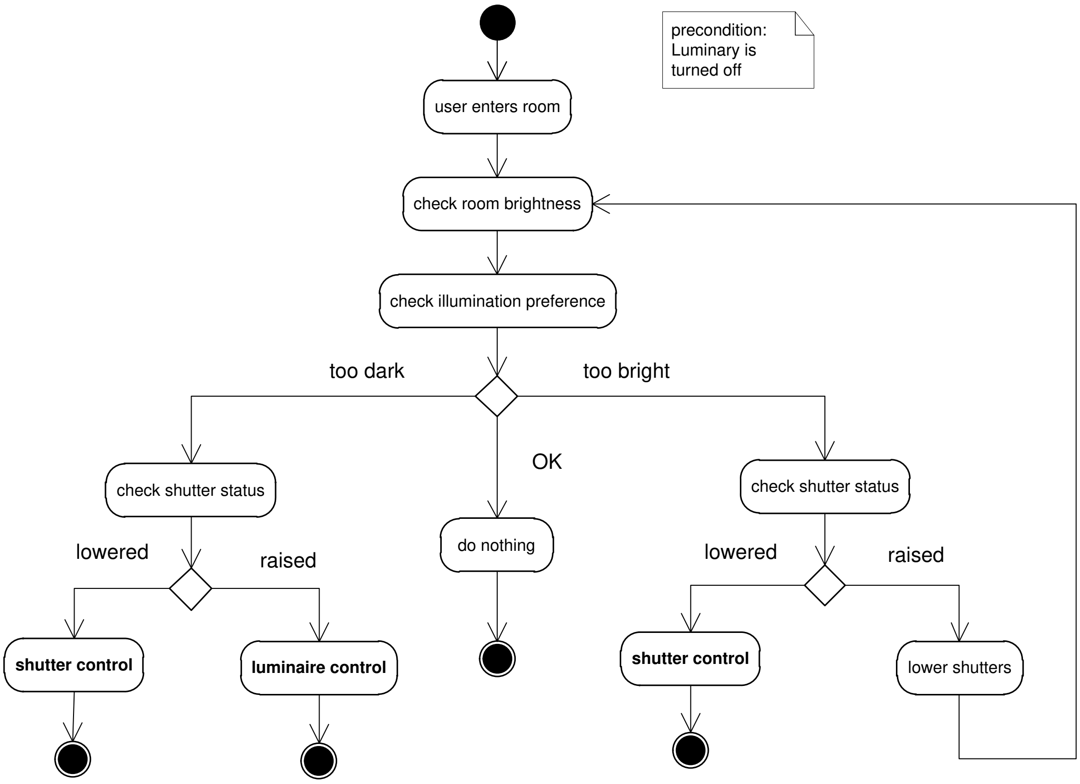

Diagram 18: Ensure Visual Comfort Activity Diagram

Shutter Control

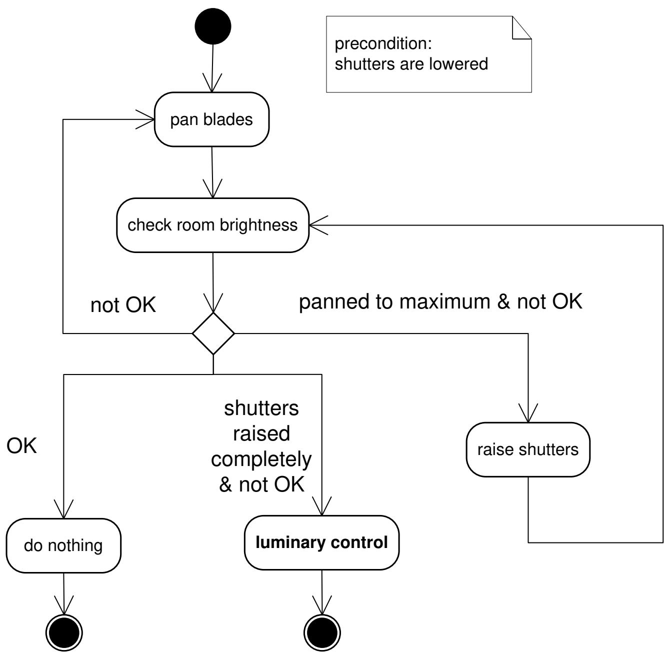

Diagram 19: Shutter Control Activity Diagram

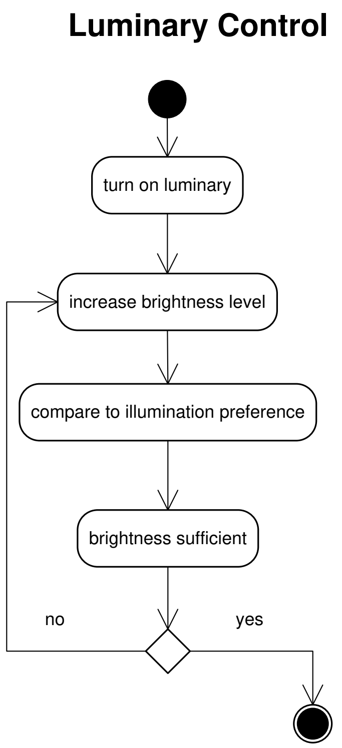

Diagram 20: Luminary Control Activity Diagram

There are several features to enhance the energy efficiency of the luminary used, which are included in the use case "*Ensure Visual Comfort*". Similar to "E*nsure thermal comfort*", this is just a basic version of what the smart home is capable. The following use cases are an addition to this one and are described in more detail to emphasize the potentials in reducing energy effort.

Turn off artificial lighting when the daylight is sufficient

This use case's primary goal is to reduce energy efforts by deactivating artificial lighting when it is not needed. The secondary objective is to increase the visual comfort for the user.

The system checks the room brightness periodically. If the luminary is turned on and the outside brightness is rising, then the intensity of the artificial lighting is reduced as long as the preferences of the inhabitant are still met. If it is possible the luminary is even turned off completely.

This use case may be of use when the user is up early and the sun light is not sufficiently intense or when the sky is brightening up.

Use Case Summary:

Name	**Turn off light when the daylight is sufficient (Adapt artificial lighting to daylight intensity)**
Goal	• Reduce energy effort • (Increase visual comfort)
Summary	If the room brightness is too low and the brightness outside of the house is sufficient to illuminate the room according to the user's preferences, the

	artificial lighting is dimmed or completely shut down.
Actors and Stakeholders	• User • Luminary • Indoor sensors • Weather sensors
Parameters	• Lighting preference • Outdoor brightness • Indoor brightness • Luminary status
Pre condition	• Luminary is turned on
Post condition	• Room brightness matches user's preferences

Adjust shutters to strength of sun insulation

This feature is already of common use in office buildings and of course will find its way to residential buildings as the houses get smarter. This use case takes into account that rooms are warming up if the sun shines directly through the windows and the sun insulation is too high. Especially when the room is already cooled by the air condition this is contra-productive.

The system checks if the house is currently cooled and if the sun insulation is high. If that is the fact, the shutters of the rooms are closed automatically to prevent the rooms from heating up. If no user is in the room the shutters are closed completely. If a user is currently in the room the shutter blades are panned to a position where they can lead a part of the sun light to the ceiling to increase the visual comfort and reduce the need for artificial lighting.

This use case can also be applied when the shutters are down and the room is currently heated. If the sun insulation is high then the system raises the shutters. Of course, the smart home only raises them if nobody is in the room currently. Otherwise, it has to check first if the preferences of the person do not collide with raising the shutters. When the sun insulation can pass through the window, the heating of the room can be reduced to reach the desired temperature.

Use Case Summary:

Name	**Adjust shutters to strength of sun insulation**
Goal	• Reduce energy efforts • Increase visual comfort
Summary	The system checks if it is in cooling period. If the sun insulation on a window is too high, the shutters go down to prevent the room from heating up and exceeding the user preferences. If a user is in the room the system ensures his visual comfort by leading natural light to the ceiling. If no user is in the room the shutters are completely closed.
Actors and Stakeholders	• Weather sensors • Indoor sensors

	• Shutters
Parameters	• Outdoor brightness (sun insulation) • Indoor brightness • Shutter status
Pre condition	• Shutters are raised
Post condition	• Shutters are lowered • (Blades are panned to specific angle)

Tinge windows when sun insulation is high

As already mentioned in the use case "*Ensure Thermal Comfort*", this measure can increase visual comfort as well. The tinging of windows is achieved by a so called switchable glazing which reacts to electric impulses and turns the glazing darker if the current sun insulation is too high. This reduces warming up of rooms significantly. Also room brightness can be decreased steadily and still provide a better view than when the shutters are lowered.

Dim light according to user's preferences

Every inhabitant of the house has its own optimal illumination level stored with his user preferences. When the system recognizes a user in a room, the light is dimmed or increased to match his preferences. This may lead to a reduction in energy consumption because not everybody needs the full potential of the lighting every time. For example people may want the light less intense early in the morning and want a brighter room when eating dinner in the evening. Also special lighting for some activities like watching TV is possible. This case is covered in the fourth user story when the family gathers in the living room watching TV together.

In our scenario of a single person household, this is simple to realize, but in houses where two or more persons live, additional collision detections must be implemented.

One possibility is that there are priority settings saved for every user and the light in a room is adapted to the preferences of a user with the highest priority. But this surely is kind of unfair for everyone except the first on the priority list. This may be an interesting choice as addition to another collision system. If somebody does not care that much about his lighting preferences he can state that others have a higher priority in their lighting preferences. An option that might work better would be to give the user with the highest light intensity the precedence. So there would not be the case that somebody may have too less brightness for reading a book. A disadvantage may be that if somebody has sensitive eyes he might be disturbed by the light intensity or that this may disturb another person who is watching a movie in the same room. A possibility would be to get all the lighting preferences of all persons in a room and compute the average of the lighting intensity. But this may only work if all are doing a similar activity (e.g. watching TV or eating together).

If the inhabitants are doing different activities in the same room another method can be used. In this example the room is equipped with different light sources. They are placed on the ceiling or are "stand alone" lamps placed on tables or are torchieres. If the system recognizes that a user is reading a book, while for example the other is watching TV, the light next to the one watching TV is dimmed for a better movie experience. The light source next to the other person is increased so he can read a book without problems.

Use Case Summary:

Name	Dim light according to users preferences
Goal	• Increase visual comfort • (Reduce energy efforts)
Summary	Every member of the household has his personal illumination preferences stored and the system adapts the artificial lighting according to them.
Actors and Stakeholders	• User • Luminary
Parameters	• User's preferences • Room brightness • Luminary status • User activity
Pre condition	• Artificial lighting is turned on
Post condition	• Brightness level matches user's preferences

3.2.6.2 Morning Illumination

This use case is a special version of the *Ensure* V*isual Comfort* use case. The most important difference can be seen in the starting point and the brightness preferences. In *Ensure Visual Comfort,* the use case starts when the user enters the room; here the starting point is some point before the alarm rings while the user is already in the room. Also the brightness is not adjusted immediately but is increased bit by bit.

The user story *Morning Routine* starts with a use case called *Morning Illumination* which is clearly a comfort feature with just a small potential for energy saving. The inhabitant likes to get up with a brightened room because it usually keeps him from feeling too comfortable in his bed and therefore he gets up faster. He has stored his preference of the room brightness at the moment the alarm rings as well as the speed of the room's brightening. With that information the system computes the correct time to start illuminating the room.

In case of this household the shutters were closed in the night due to security preferences of the inhabitants and to ensure their comfort so they cannot be disturbed by outside lighting at night. Now, the system checks the personal preferences of the sleeping inhabitant (growth of brightness over time, light intensity), the actual brightness outside as well as the estimated natural brightness when the user wakes up. The alarm time is also checked. According to these values the optimal timing for opening the shutters is calculated. Every few minutes the current and estimated outside brightness and also the room's brightness are measured and computed again to adapt to a possibly changing weather condition. According to those values the shutter blades pan every few minutes a bit further until the desired visual comfort is reached when the alarm rings.

The above scenario of course is the simplest one. It is becoming more complex when it is completely clouded or partly clouded outside or most complex when the weather condition is changing fast. In the first case, when the sky is overcast and the outside brightness is not enough to sufficiently brighten the room, the indoor lighting can be used to gain the desired light intensity. But not only on cloudy days, also when the user gets up pretty early when sun has not risen this can be used as an option.

A problem occurs when the outside brightness is measured just when the sun breaks through a hole in the cloud ceiling. A solution for this may be to increase the measurement interval or to match the houses weather sensor data with weather data from the Internet. A similar situation appears in case of fast weather changes, for example, when there are high wind speeds.

When this is applied to a household with more inhabitants and more bed rooms, the adjustment is not that complex. The only difference hereby to the case already described with the single person household is a sole morning illumination for every bed room, as the other room's windows are not affected by that use case. Applying this feature to two or more people who are sleeping in the same room is more complicated. A solution is that the room is not that brightened by natural light but by every sleeper's bedside lamp. Of course, this is no perfect solution but this would be a good tradeoff.

Use Case Summary:

Name	**Morning Illumination**
Goal	• Increase comfort when waking up • (no artificial lighting needed in the morning in bed room)
Summary	A certain amount of time before the user's alarm is ringing the shutter blades are tipped bit by bit. When the room is not bright enough, the shutters are raised slowly until they are fully opened. In the event, that it is a dark and cloudy day, the artificial lighting is turned on to achieve the user's preference in room brightness when the alarm rings.
Actors and Stakeholders	• Windows • Shutters • Luminaries
Parameters	• Alarm time • Indoor brightness • Outdoor brightness
Pre Condition	• Shutters are down • Room is dark
Post Condition	• Shutters are up or blades are letting sun through (due to illumination preference) • Room brightness meets user preferences

3.2.6.3 Turn off lighting when nobody in room

One of the most important use cases regarding reduction of energy is turning off the luminary if no one is in the room. As a foundation to this, the system must know the position of the inhabitant(s) through motion tracking, which is already mentioned at the beginning of chapter 4.2. Also this use case is referred to in the *Ensure Visual Comfort* use case.

If the luminary is activated and a user is leaving a room and nobody is in it anymore, then the system dims the lighting to a minimum level. This is done to have the previous brightness settings back immediately without disturbing the eyes of the user when he comes back. The system tracks his path and activity and if he seems to remain in another room the light is shut down. The luminary is also shut down if the user keeps away for a longer time. When the system notices that he is on his way back the luminary can be increased slowly before he enters the room. This is done so that the inhabitant is not dazed by an acute increase in brightness.

Use Case Summary:

Name	Turn off lighting when nobody in room
Goal	• Reduce energy effort • (Increase comfort)
Summary	As the user is leaving a room and if the luminary is activated it is shut down to save energy. When he comes back the brightness level is set to his preferences.
Actors and Stakeholders	• User • Indoor sensors • Luminary
Parameters	• User (position, path, activity) • Luminary status
Pre Condition	• Luminary is turned on
Post Condition	• Luminary is dimmed or turned off

3.2.6.4 Control lighting in seldom reached rooms using motion sensors

Controlling the artificial lighting in rooms which are either accessed seldom or occupied just for a short time by means of motion sensors is already of common usage in office and public buildings – it is readily used if the rooms have no window or any other source of natural light. So no one can forget to turn off the light after leaving the room. Also for people with disabilities or roll chairs this is a massive increase in comfort because they need not to search for a switch to turn on the light, or have to struggle reaching a switch that is out of their range. In residential buildings, this method is worthly applied to restrooms, storerooms, cellar rooms or communal rooms in apartment buildings.

When a person enters the room the motion sensors recognizes this and turns on the artificial lighting. Any further strategy on duration of lighting depends on room size and layout. If it is a rather small room and the motion sensor can cover the whole area, then the light can be turned off as soon as no motion is detected or a short time (e.g. one minute) afterwards. If the area cannot be covered as a whole, then the time until the light is turned off should be increased because somebody may still be in the room without the system's awareness.

Use Case Summary:

Name	Control lighting in seldom reached rooms with motion sensors
Goal	• Reduce energy efforts
Summary	If a person enters the room (area) and the motion sensor detects that, the light is turned on. If the sensor does not detect any more movement the light is turned off after an appropriate time.

Actors and Stakeholders	• User • Motion detectors • Luminary
Parameters	• Motion sensed • Luminary status (turned on/off)
Pre Condition	-
Post Condition	• Lights only activated if room is occupied

3.2.7 White Ware & Small Appliances

This chapter deals with energy intense devices. The use cases allow saving energy when using coffeemakers, ovens and hotplates, washing machine and tumble dryers as well as other appliances that are used in households. Again, next to the primary goal of reducing the energy efforts also the improvement of comfort can be seen as an option.

3.2.7.1 Coffeemaker heats only water when user needs it

To serve the fact that fully automated coffee makers are becoming more and more popular, this can be an important use case to achieve a significant energy reduction. These machines need a high amount of power for heating the water to provide a quick reaction when the user wants a coffee. Only a small percentage of the users just turn it on when they want a cup (due to the fact that it takes up to 3 minutes until the coffee is finally in the cup). Some people may turn it on in the morning and let the machine activated until they go to sleep (or even longer). So, most of the time, the appliance is activated unnecessary.

In the first User Story the system knows the typical amount of time the user needs between the alarm clock ringing and he is being in the kitchen ready for having breakfast. The coffee maker is activated in time to provide hot water when the user needs it. This method can be enhanced when the system is watching the current activities and matches it with the user's typical routine. For example if the user is entering the bath and activates the shower – although he is doing this rarely – the coffee maker can be turned on later.

Another additional option would be that the coffee maker could sense if there is a cup under its nozzles. If that is the case the coffee can already flow into the cup as soon as the user enters the room where the appliance is situated. This saves the inhabitant's precious time and he can have his coffee earlier.

Another possibility is to store the typical usage times of the coffee maker, like during breakfast or every time when the user gets home from work. According to these times, the coffee maker is powered up and the water is heated. Outside these timeframes, the device has to be powered up manually to get a cup.

The part above takes care of comfort aspects. The next part describes strategies to decrease the energy consumption. A simple rule for the system is to shut down the device when the user leaves the house. To cover scenarios where he gets back quickly – like when he is putting out the garbage or clearing the mailbox – the coffee maker can be powered down simply 5 minutes after he left the room. Of course, this value can be edited by the user. The increase in energy efforts is justifiable allowing for the increase in comfort.

Use Case Summary:

Name	Coffeemaker heats only water when user needs it
Goal	• Save energy • Increase comfort
Summary	The system stores the usage times of the coffee maker and activates it during these typical timeframes. The coffee makes is also turned on/off on special events (user wakes up, user leaves house, user enters house after work …) which the system figures out by monitoring and analyzing the user's behavior.
Actors and Stakeholders	• Coffee Maker • User
Parameters	• Device usage times • Device turned on/off
Pre condition	-
Post condition	• Coffee machine only activated when required (which leads to energy savings and comfort)

3.2.7.2 Oven

These use cases cover several areas concerning ovens and cook tops including energy reduction, safety or comfort.

Turn off (notify) after certain time of activeness

When a hotplate is active for a longer period of time and it is obvious that the user stopped cooking, the user is notified that the hotplate will shut down in a few minutes. If this is intended by the user he can override the turn off automatism. The notification is either by acoustic means or if a display is currently activated next to him than also a message can appear additionally. This has the potential to save a lot of energy that is currently wasted by the negligence of people.

Turn off when user is sleeping / leaving the house

The oven and the hotplates are turned off automatically if it is not needed any more. If the system senses that the user leaves the house it is obvious that he forgot to turn off the oven and the system is doing that automatically. Also he can be notified about that before he leaves the house. The system also turns off the oven if the user is currently in his bedroom and has not moved for a while, so it can assume that he is sleeping. This case may happen very seldom but it increases safety and reduces energy efforts as well.

Heat area of hotplate where pot is

When the hotplate is activated by the user the system senses which area of the hotplate is covered by a pot and only heats this part. So, no heat is wasted if a pot is smaller than the predefined area.

Watch if pots have cover

When the user is putting a pot on the hotplate and activates it, it checks if all pots have a cover. If one pot has no cover on it, then the system notifies the user about that fact. If this is intended by the cook that he can either specify this before he turns on the hotplate or ignores the notification. A lot of energy that is used for e.g. cooking water can be saved in this way because heat, which is produced during the cooking process, remains in the pot so just about one third of the power is used to get a pot with 1.5 liters of water cooked.[30]

Watch food on oven if it over boils

The food on the hotplate (and also in the oven) is monitored when it is cooked. If the food tends to overboil, then the heat of the hotplate is reduced to an appropriate level. The user is notified that the heat is reduced because otherwise the food would overboil.

Notify user when cook top is active but no pot on it

When a cook top is turned on and there is no pot on it, the user is notified. If the user does not react to this call, the cook top is turned off after a certain amount of time.

The following use case and activity diagram shows a part of the mentioned features of the process of cooking in a smart home. The user is preparing the food and putting it in the oven or on the hotplate. The system monitors if it does not overboil, or gets burned.

[30] http://derstandard.at/3050150/Jeder-Topf-hat-seinen-Deckel, 2010-09-01

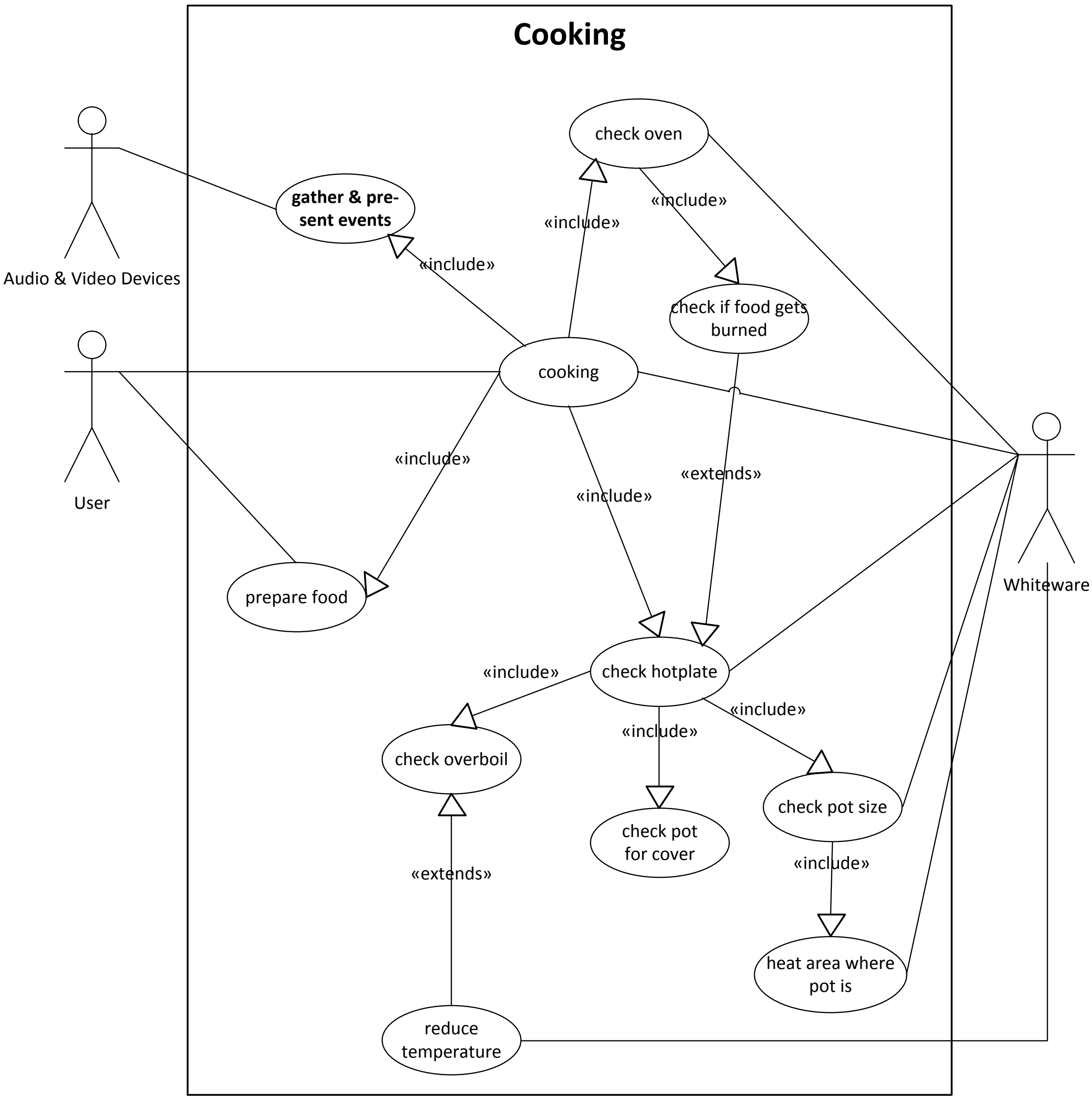

Diagram 21: Cooking Use Case Diagram

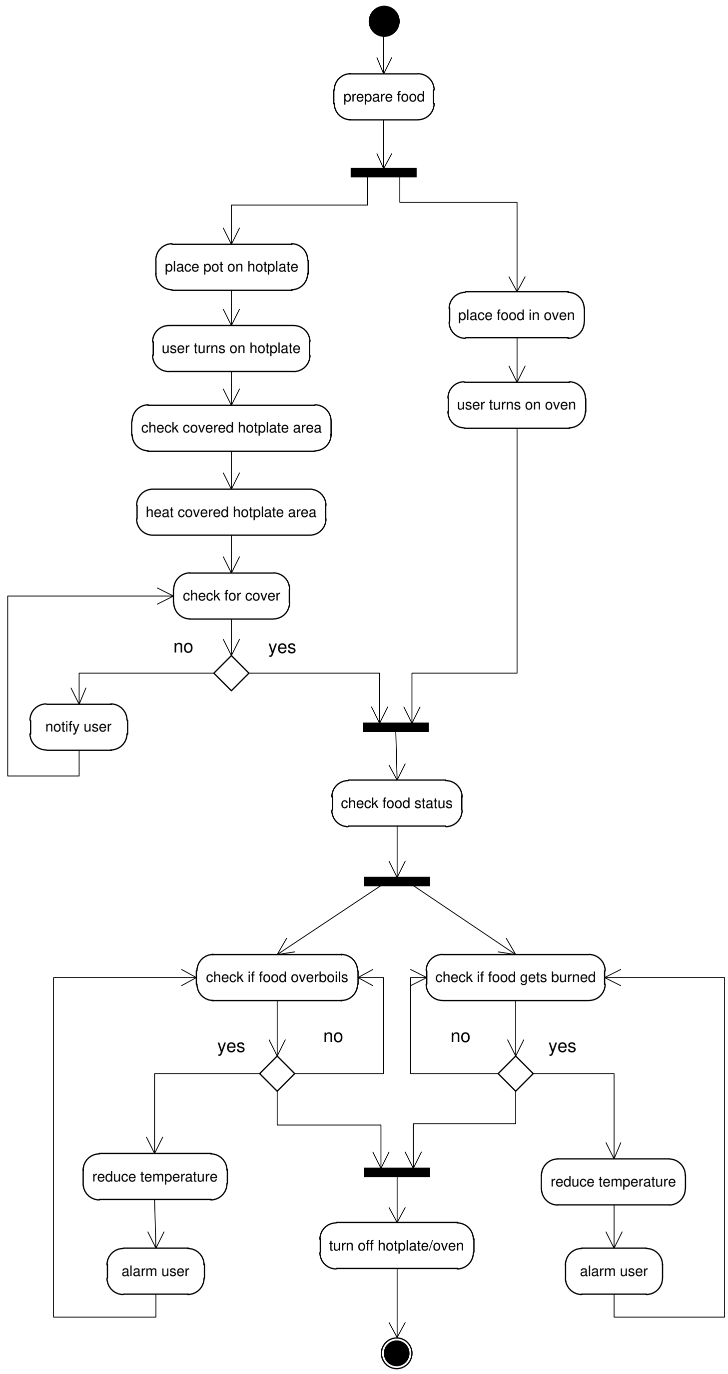

Diagram 22: Cooking Activity Diagram

Use Case Summary:

Name	Cooking
Goal	• Save energy • Increase comfort
Summary	If food is on the hotplate or in the oven, the system checks the pot size and whether all pots have a cover. It only heats the area of the hotplate where the pot is and notifies the user if the pot has no cover. While cooking the system checks if the food is not overboiling or burned.

Actors and Stakeholders	• White Ware (oven) • Audio & Video Devices • User
Parameters	• User's position • Food status • Pot size • Pot status (cover)
Pre condition	-
Post condition	-

3.2.7.3 Turn off energy consumers when the user leaves the house / is sleeping

Another important feature in reducing the energy effort is by shutting down all devices and appliances that are still running. The use case is triggered if every person left the building, or all inhabitants are already in their bed sleeping. First the system checks if there are devices programmed for an activity – e.g. the recorder is programmed to record a TV show. Those devices are either not shut down or the system schedules to reactivate them a short time before the program is starting.

The system pursues a hierarchical approach. First of all the device is put into standby mode if there is one implemented. As there are a lot of devices and appliances that do not possess the ability of an energy saving mode, these are shut down by the system. The last level is to separate the devices from the power net by shutting down the socket where it is connected to. This is useful if some devices consume more energy than necessary in standby mode. Also appliances that do not need to e.g. save the current time because they have a clock on their display, or retain settings do not waste energy any more.

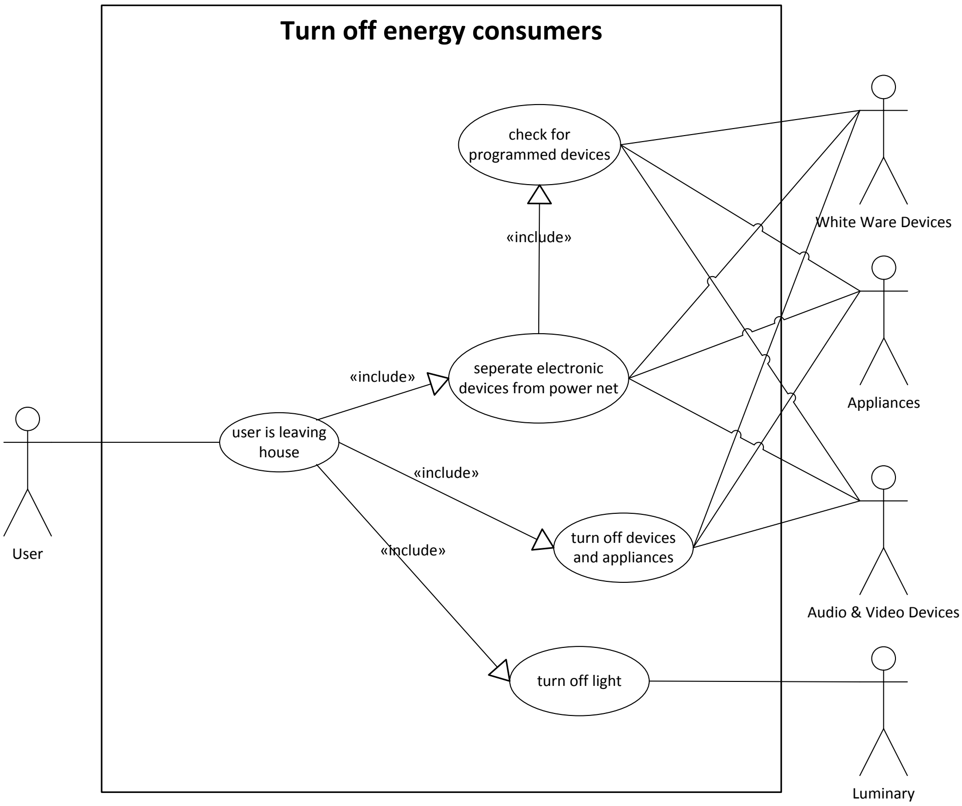

Diagram 23: Turn off energy consumers Use Case Diagram

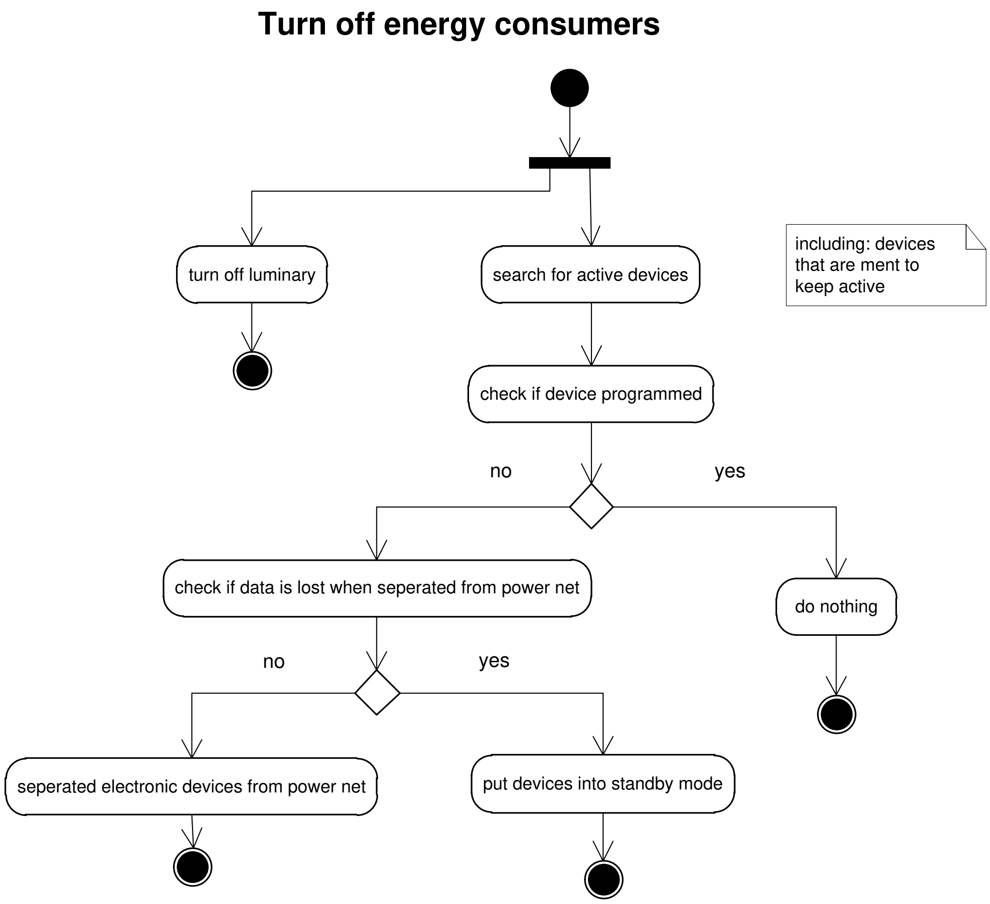

Diagram 24: Turn off energy consumers Activity Diagram

Use Case Summary:

Name	Turn off energy consumers when the user leaves the house / is sleeping
Goal	• Reduce energy effort
Summary	This use case is triggered if the user leaves the house or if the system recognizes that the user is sleeping. Devices that are still turned on are turned off as they are not needed by the user when he is not at home. Exception for recorders
Actors and Stakeholders	• User • Electrical energy consuming devices
Parameters	• User position or action • Device status (turned on/off) • Device usage
Pre condition	• Devices are turned on
Post condition	• Devices are turned off (or in standby mode)

Name	Separate devices from the power net
Goal	• Reduce energy effort (eliminate unnecessary standby consumption)
Summary	After all inhabitants leave the smart home, electronic devices that are not necessary or should be activated either the whole time or for a specific time before the user is back, are separated from the power net.
Actors and Stakeholders	• User • Electrical energy consuming devices
Parameters	• User position or action • Device status (turned on/off) • Device usage
Pre condition	• Devices are in standby mode • Devices are turned off
Post condition	• Devices are separated from the power net

3.2.7.4 Activate washing machine

This use case includes several features that intend to reduce energy efforts of washing machines and also make use of the house's own power production capabilities. These could either be photovoltaic or wind energy or any other energy sources that are installed in the house.

The use case starts after the washing machine is filled with clothes and a washing program is selected. After that the system checks numerous parameters. It checks the current sun insulation if a photovoltaic power producer is used or the current wind speed if any kind of wind mill is attached to the house and verifies the actual energy gain. Now, the weather forecast is checked and if there can be more energy provided in the near future due to weather changes. Of course, this should only be calculated for the next couple of hours, so the user can get his washed clothes in time. The system compares the power gain with the power usage of the washing machine and if it needs more than can be provided by the house itself - which might be the case most of the time, because they are very energy intense – the start is postponed to a time where the power producers can provide more energy than currently.

In the second user story *Coming Home*, the washing machine is filled in the evening after work. So the sun insulation was not that much and the system decides to shift the start to the next day when the full potential of the photovoltaic plant can be used. It notifies the user about the shifted start and why the original programming is altered. The display may also show a calculation how much energy is gained from own production, how much is needed from the power supplier and the amount of money/energy that is saved. If the user is unhappy with this decision he can change the starting time to a more appealing time. He may also be able to give a time when the machine needs to be done with its wash cycle. To achieve this, the system has to calculate the time the current washing program needs to complete. Another possibility would be that the smart home shifts the start of the program to the night – when the energy provider offers a cheaper night tariff. Another possibility to enhance this may be to check if the user will be at home when the program is ready, so the wet clothes will not be in the machine for a longer time.

A pretty similar approach could be used for clothes dryers. Not just are energy consumption and location nearly the same, also the inhabitant's activities in using them are similar.

Use Case Summary:

Name	**Turn on when energy is cheaper**
Goal	Reduce energy effort
Summary	When the user activates the washing machine and selecting a washing cycle the system checks the current time of the day. If the energy provider has a cheaper charge on a different time of this day the start time is shifted to this point in time. The altered startup time and reason is presented to the user.
Actors and Stakeholders	• Washing Machine or dryer • Energy Provider
Parameters	• Energy tariff • Time of day • Duration of washing cycle • Energy consumption of machine
Pre condition	• Clothes in machine
Post condition	• Clothes washed with cheaper tariff

Name	Supply washing machine with own energy plants
Goal	Reduce energy cost
Summary	The start of the washing program is shifted to times, when the house's own power plants can supply the washing machine as much as possible. Therefore the actual weather conditions and the actual energy gain are checked. Also the weather prediction is fetched and the possible energy gain is calculated.
Actors and Stakeholders	• Washing machine or dryer • Energy Producer • Energy Provider • Weather Sensors • Weather Forecast
Parameters	• Current Weather (sun insulation) • Weather forecast • Energy tariff • Time of day • Duration of washing cycle • Energy consumption of machine
Pre Condition	• Washing machine uses energy delivered by power supplier.
Post Condition	• Washing machine used mainly energy produced by houses own power producers to fulfill its task.

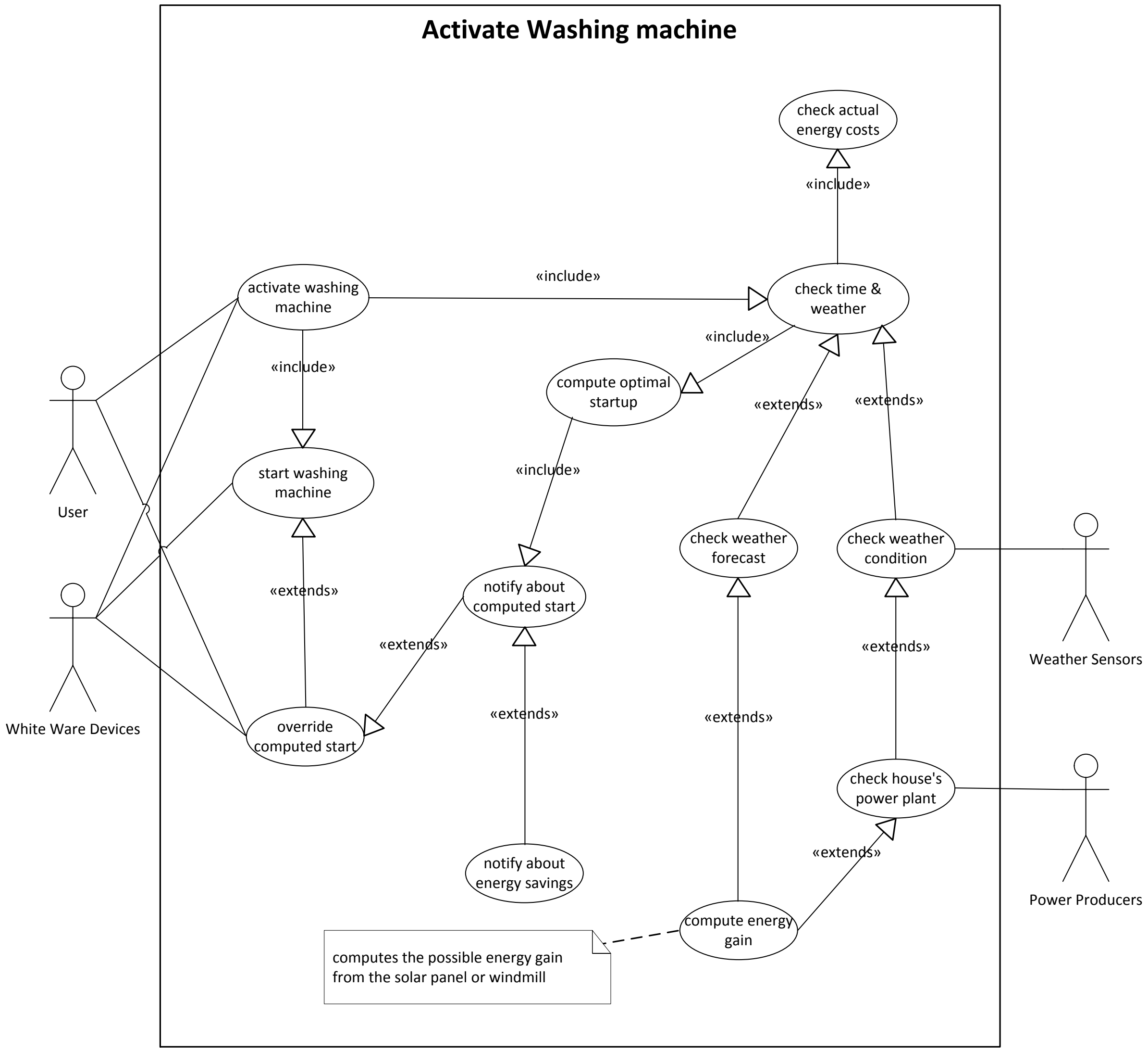

Diagram 25: Activate Washing Machine Use Case Diagram

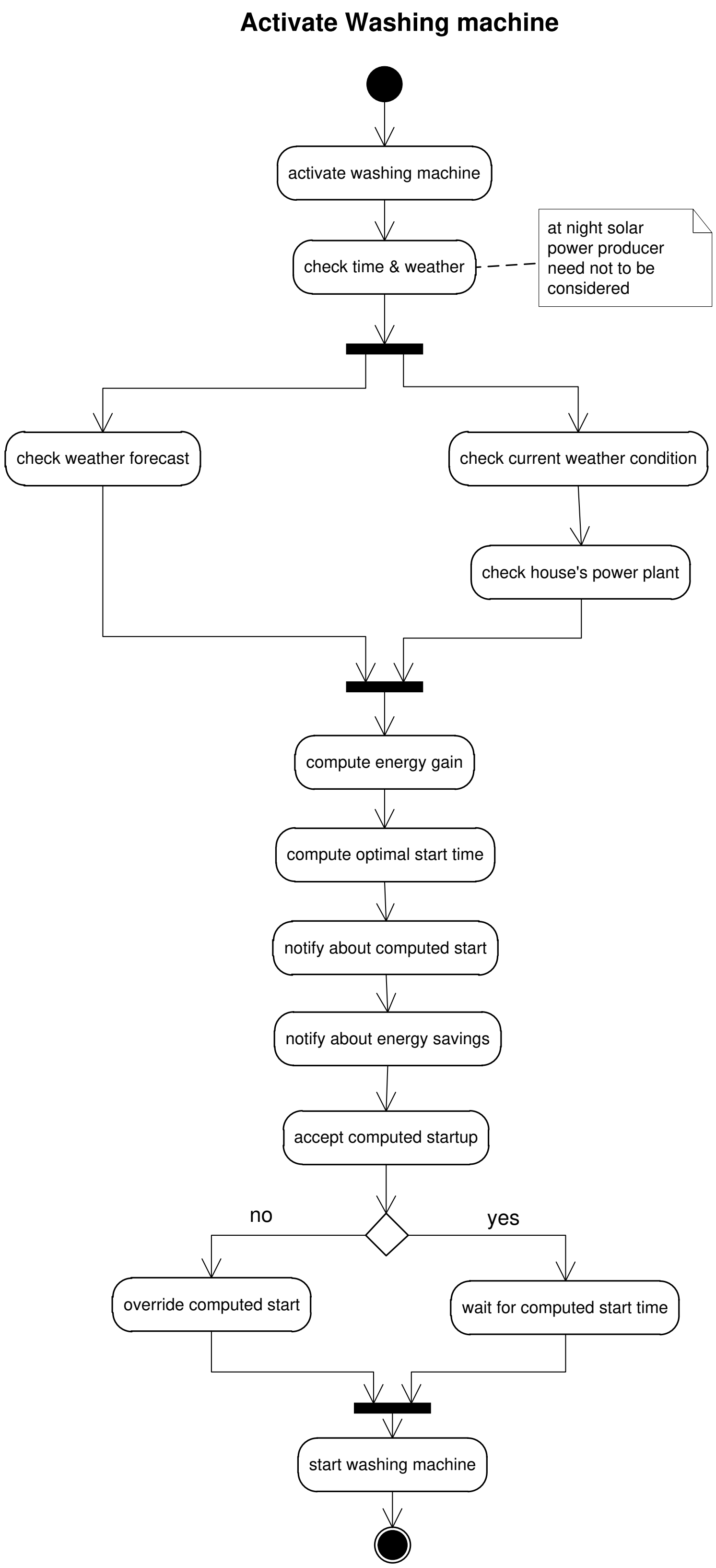

Diagram 26: Activate Washing Machine Activity Diagram

3.2.8 Brown Ware Devices

This chapter lists various use cases concerning brown ware devices. Due to the increase increasing amount of such devices and the energy that is consumed by them there is a lot of potential to save energy. Also a lot of features can be applied to such devices to fulfill the user's comfort.

3.2.8.1 TV & Radio Control

In this use case, TVs or more generally displays as well as speakers (from TV, PC or radio) are controlled.

One kind of energy consumer, that's becoming more and more important in his share of energy expenditures in domestic buildings, is the TV. Especially when the size of TV screens is increasing as much as it is currently the fact, the TV will become a great part in energy consumption of a household. A new common 32" LCD TV requires between 71 and 143 Watts per hour (production between 2008 and 2010)[31] going up to 260 watts per hour for screens with a size of 42". Although many products include dimming and energy saving features, the TV just does not know when it is suitable to activate them. In the case of computer monitors, it is reasonable to shut it down after no interaction was there from the user. On the end consumer market a monitor is available that is already equipped with a motion and brightness sensor, so the screen brightness always fits to the ambience brightness and it is automatically shut down when nobody is sitting in front of it (Eizo EV2303WH-BK[32]). One method – the brightness sensors – is also suitable for TVs but the second one, which has the possibility of saving a huge amount of energy, cannot be implemented that easily into a normal home because the distances are far too big for motion sensors that are attached at such a device.

In our user stories, the TV and radio program is an important factor in the user's routines. For example he is sitting in the living room, drinking a cup of coffee and watching TV. As the smart home is already aware of the user's position it knows when he leaves the room and shuts down (or dims) the backlight of the screen, which has a big share of the whole energy used. As soon as the user enters the room again, the backlight is switched on again and the brightness condition is restored to its previous settings.

One method to enhance this would be if the system recognizes the current activity of a user. In the previous case the system just needs to know where the user's momentary position is. An improvement can be added to the system if it recognizes when the user is doing something that is more time consuming than e.g. fetching a cup of coffee in the kitchen. As the smart home is able to recognize what a user is currently doing, the energy consumption of a TV can be decreased further. If the system assumes that the user is away for a longer time like when he is clearing the washing machine and then filling it up again it can shut down the TV completely or put it into a standby mode. So it cannot happen that a TV is turned on while nobody is watching.

But this may not entirely fit the user's comfort; some people still want to hear the sound of the TV show or program even when they are not in the room where the device is situated. The smart house is equipped with speakers in every room. They are used for system notifications or the door bell but are also useful in this case. As the system knows the room where our user currently is sojourning it redirects the audio output to these speakers. But to enhance this the smart home is also equipped with multi functional displays in several rooms, like in the kitchen or the bed room. If the user is situated in such a room, the video output can also be redirected to that screen. The same method can be used to broadcast a radio program or music the user wants to hear.

In a multi-person household, this may lead to controversies between those people.

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[31] http://reviews.cnet.com/green-tech/tv-consumption-chart/, 2010-07-14
[32] http://www.eizo.de/monitore/flexscan/ecoview/23-zoll/EV2303W.html, 2010-07-14

Use Case Summary:

Name	Dim backlight when user leaves the room
Goal	• Reduce energy effort • Spare backlight
Summary	When the user leaves the room for a short time (which is estimated by his activity) the TV's backlight is shut down. If he comes back the backlight goes to its previous intensity immediately.
Actors and Stakeholders	• Audio & Video Device (TV) • User
Parameters	• User position • Device status (on/off) • Location of speakers/displays in house
Pre Condition	• TV/radio is turned on • Backlight at user's preferences
Post Condition	• Backlight is dimmed (turned off)

Name	Shut down output device when nobody in room
Goal	• Reduce energy effort
Summary	If the user leaves the room and any output device like a TV/display or speakers are active then they are shut down to save energy.
Actors and Stakeholders	• Audio & Video Device (TV, radio) • Speakers • User
Parameters	• User position • (time away)
Pre Condition	• Speakers and display are turned on
Post Condition	• Speaker and display are turned off

Name	Redirect video/audio output to current location
Goal	• Increase comfort
Summary	If the TV or radio is turned on the audio output is redirected to speakers in the room where the user currently is. If another display is located in the room the video data is redirected as well.

Actors and Stakeholders	• Audio & Video Device (TV, Radio) • User
Parameters	• Room equipment • User position (location, path) • User preferences
Pre Condition	• Speakers and/or display at user’s position are turned off
Post Condition	• Speaker and/or display at user’s position are turned on

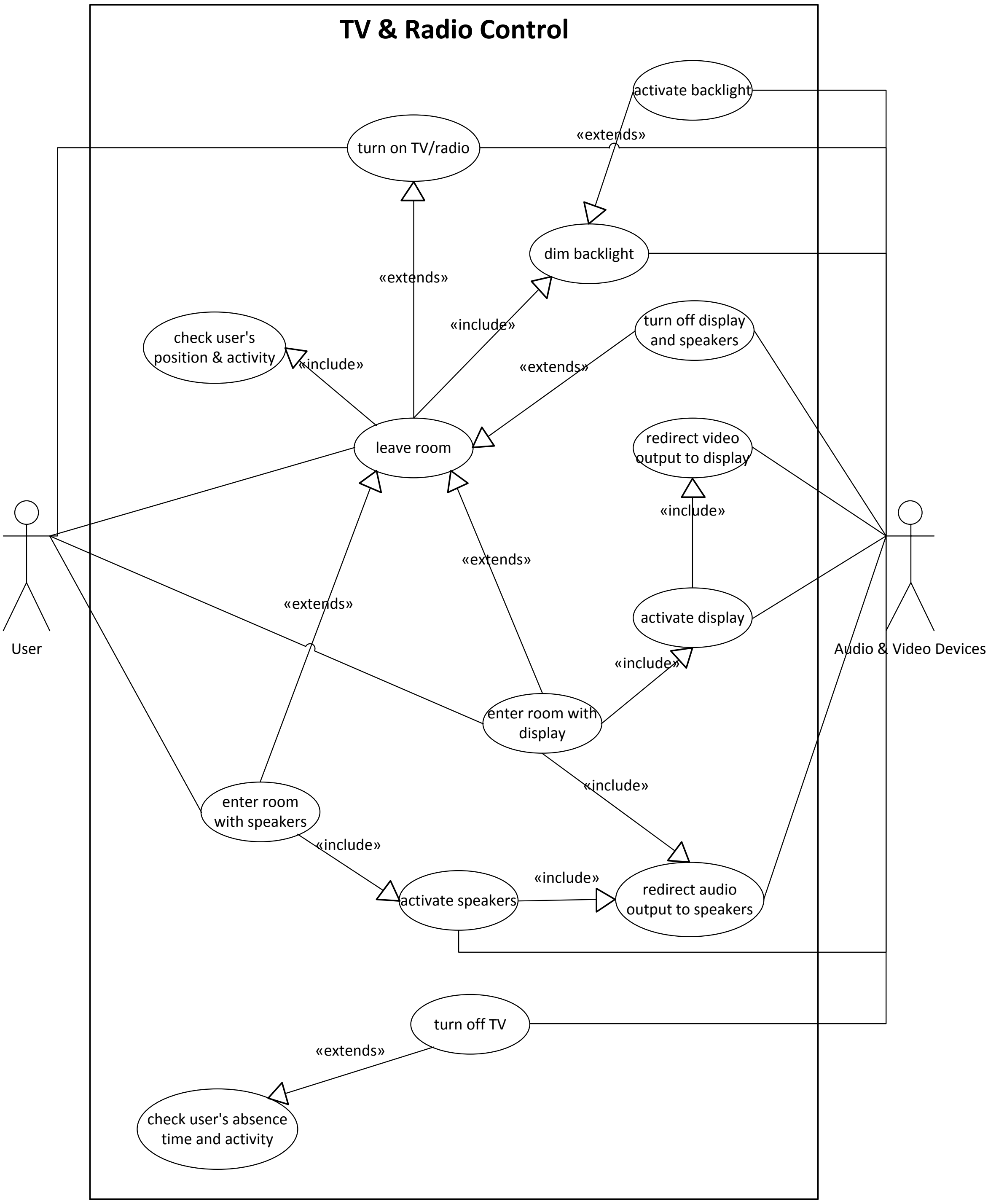

Diagram 27: TV & Radio Control Use Case Diagram

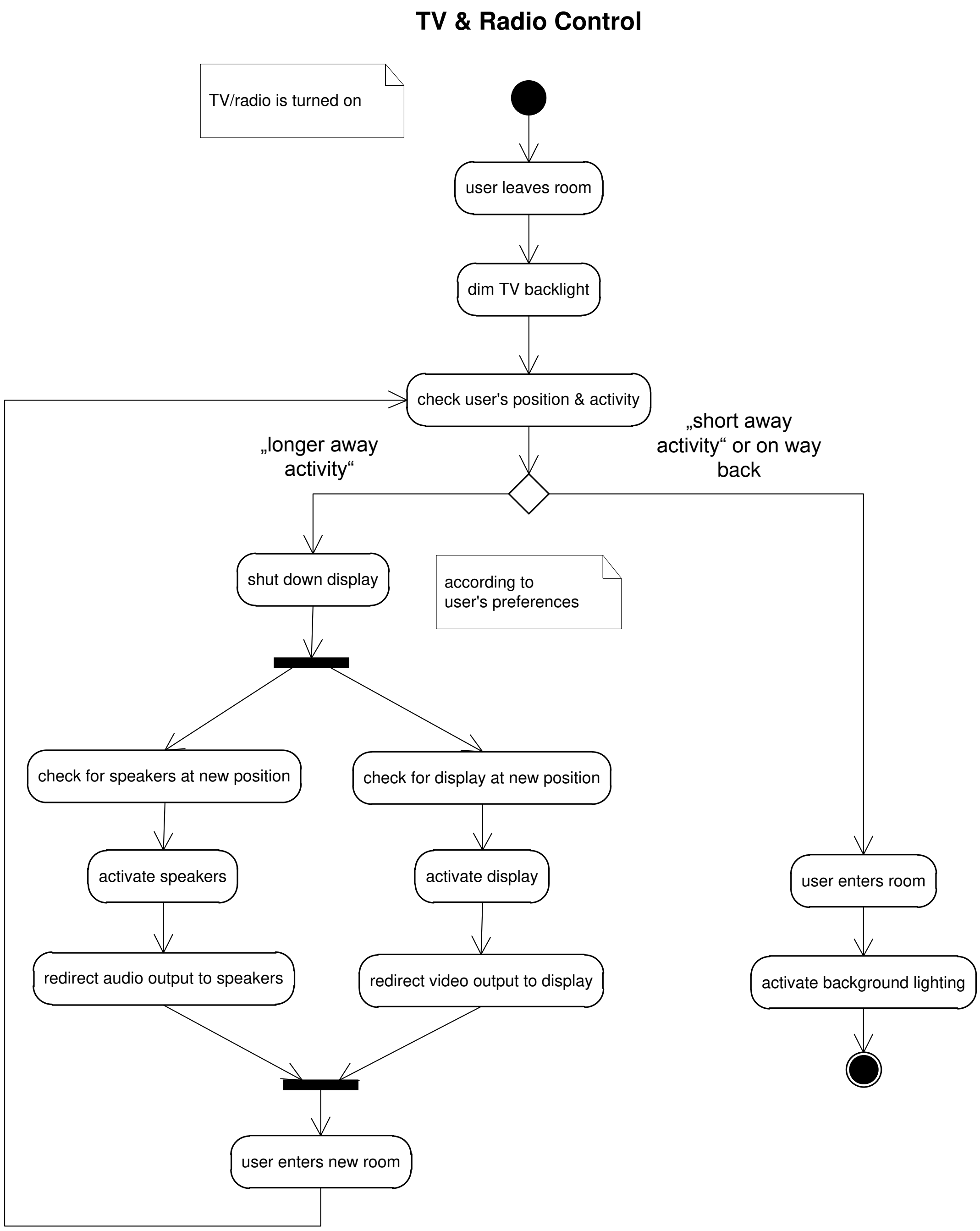

Diagram 28: TV & Radio Control Activity Diagram

3.2.8.2 Adjust display brightness to room brightness

When the display is activated the smart home senses the actual room brightness. Additionally it checks the user's preference of the display brightness which may vary from user to user. If the brightness of the display can be reduced without decreasing the user's comfort this is done. Otherwise if the display brightness is too low it is increased to fulfill the watcher's comfort.

Use Case Summary:

Name	Adjust Display brightness to room brightness
Goal	• Increase comfort • (Reduce energy effort)
Summary	The smart home adjusts the display brightness to the actual brightness in the room regarding the user's preferences.
Actors and Stakeholders	• Audio & Video Devices (TV, other display) • Indoor Sensors
Parameters	• Room Brightness • Display Brightness • User's preference
Pre Condition	• Display brightness at factory settings
Post Condition	• Display brightness adjusted to room brightness

3.2.9 Sanitary

As opposed to the other chapters here is no electrical energy of fossil fuels are saved. This is the only chapter where water saving is the main goal of all use cases.

3.2.9.1 Various use cases for sinks, water basins, showers and bathtubs

Close faucet when water running longer than specific time

If the user opens a faucet and the water flows out of it longer than a specific time the user is notified about that fact. If the user does not react to that then the faucet is closed automatically.

Close faucet when specific water height is reached

If the water reaches a specific height in the bath tub or a sink, then the system closes the faucet to prevent overflowing of the water. The user is notified that the faucet is shut down and that the water reached maximum height.

Set ideal temperature for warm water

Every inhabitant has stored his ideal water temperature for a bath or a shower. When the user draws a bath or is taking a shower the system automatically adjusts the temperature of the water to reach the desired value. The water temperature can also be set to a maximum temperature which can vary according to the season, because most people need less water temperature in summer or warmer month.

Set ideal water amount to user's height and mass

When the user draws a bath, the system checks which user is taking the bath. Because the body mass and height is stored the system adjusts the water amount. When a person's body size is not stored it could be entered or an average body is taken as measure.

3.2.9.2 Close water conduit when user is sleeping or leaving the house

A method to reduce water usage of the smart home is to shut down the main water conduit to prevent loss of water from dripping faucets. This action is made when the user either is already asleep or when he left the house. First the system checks if there are any devices programmed during the user's absence time that may need water like the washing machine, the dish washer or even an automated irrigation plant. If there is nothing programmed then the smart home closes the main water conduit.

Just one slightly dripping faucet can cause a water loss of about 36 liters a day and a running toilet up to 700 liters a day[33], which is over 13000 liters a year for the faucet and the huge amount of 255500 liters a year for the running toilet. This may not be an actual problem in central European countries with a great amount of natural water reserves but in countries that are not blessed with that natural amount of drinkable water this can lead to significant savings also in energy by requiring less water to be purified. Before the conduit is closed the system checks if any device that needs water is meant to be activated during the user's absence. In the time period a device needs water the conduit is opened.

Use Case Summary:

Name	Close water conduit when user is sleeping or leaving the house
Goal	• Reduce water usage
Summary	After all inhabitants leave a house the water conduit is closed if there are no devices needing it. This is also applied when all users are sleeping.
Actors and Stakeholders	• White ware • Water conduit • User • Irrigation
Parameters	• User position • User activity • Device status (programmed or not) • Water conduit status (open/closed)
Pre condition	• Water conduit is open
Post condition	• Water conduit is closed

[33] http://www.wassernet.at/article/articleview/20182/1/5740, 02010-07-06 10:30

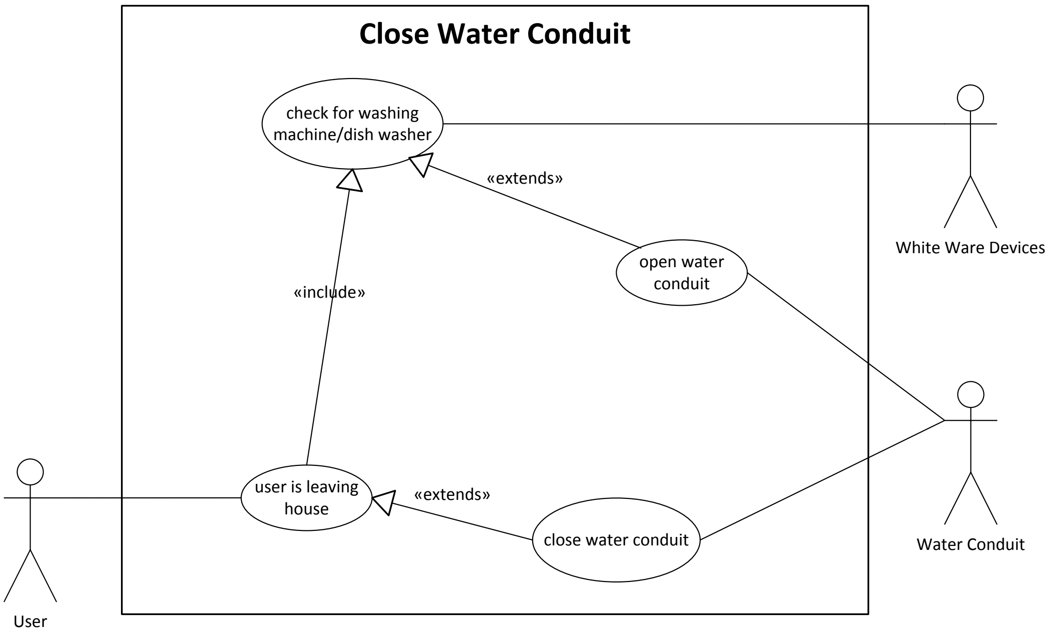

Diagram 29: Close Water Conduit Use Case Diagram

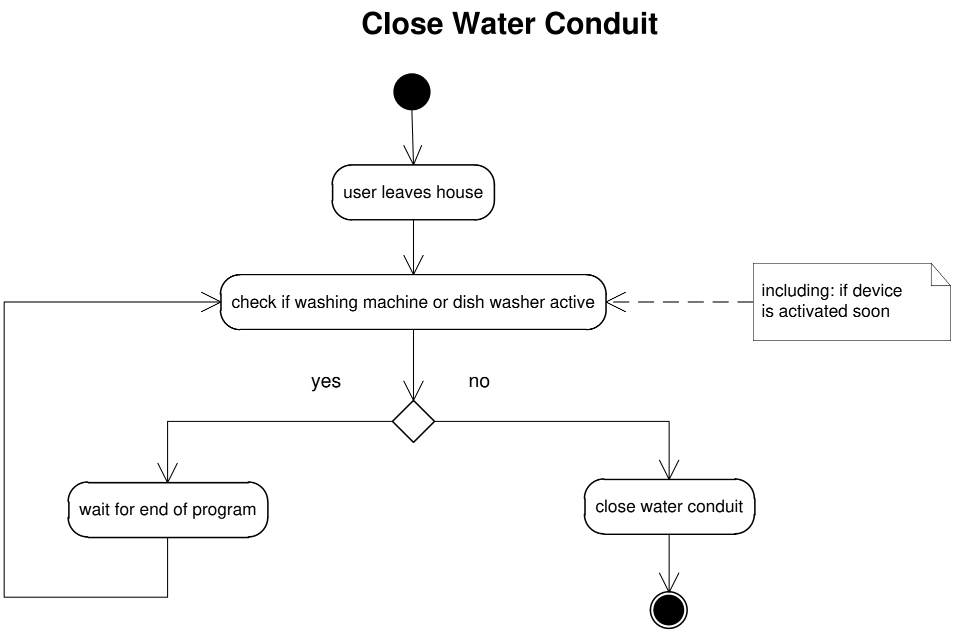

Diagram 30: Close Water Conduit Activity Diagram

3.2.10 Security

As the smart home is also equipped with a set of security measurements the increase in energy consumption can be reduced with the use of artificial intelligence.

3.2.10.1 Security-camera

Turn on, when motion sensors recognize motion

The smart home's security system consists of video cameras as well as motion sensors that cover the same area. Usually the video cameras are turned off to save energy. When the motion sensors sense somebody or something the video camera(s) that cover the corresponding area are activated. When there is no motion detected any more, the camera is turned off again after a certain amount of time.

3.2.10.2 Presence simulation

A feature to enhance the security of the smart home is the simulation of the inhabitant's presence.

As an improvement to currently available products the smart home knows the usual routine of the user. If the user always watches TV in the evening, it can activate the television for a specific time for example. It can also turn on some luminary in specific rooms or play typical sounds, which could have been recorded previously or just standard noises, from various speakers like chatter or sounds resembling domestic work.

Use Case Summary:

Name	Presence Simulation
Goal	• Deter burglars from breaking into the house
Summary	To simulate the presence of inhabitants when they are away the system stores typical patterns of them and activates certain devices, lights and audio data.
Actors and Stakeholders	• User • Luminary • Brown Ware Devices
Parameters	• User position • User routine • Time of day
Pre condition	• User not at home • No presence simulation active
Post condition	• User not at home • Presence simulation active

3.2.11 Reused Use Cases

This subchapter contains use cases or functions of the smart home that are used by several other use cases and do not fit in a certain category.

3.2.11.1 Check home coming time

This feature calculates the home coming time of the inhabitant(s). Therefore, it takes the stored schedule of the user and the typical home coming time for this weekday as a basis. From these values the expected time when the user is coming home is calculated.

Use Case Summary:

Name	**Check home coming time**
Goal	• Compute user's home coming time
Summary	To compute the home coming time for this day the system checks the user's schedule and the previous times he came home.
Actors and Stakeholders	• System: Smart Home
Parameters	• User's schedule • Typical home coming times
Pre condition	-
Post condition	• Home coming time calculated

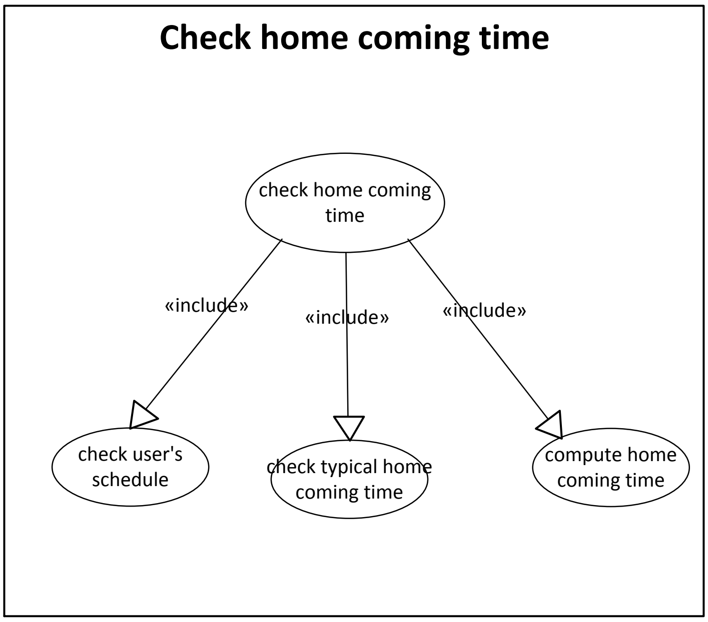

Diagram 31: Check Home Coming Time Use Case Diagram

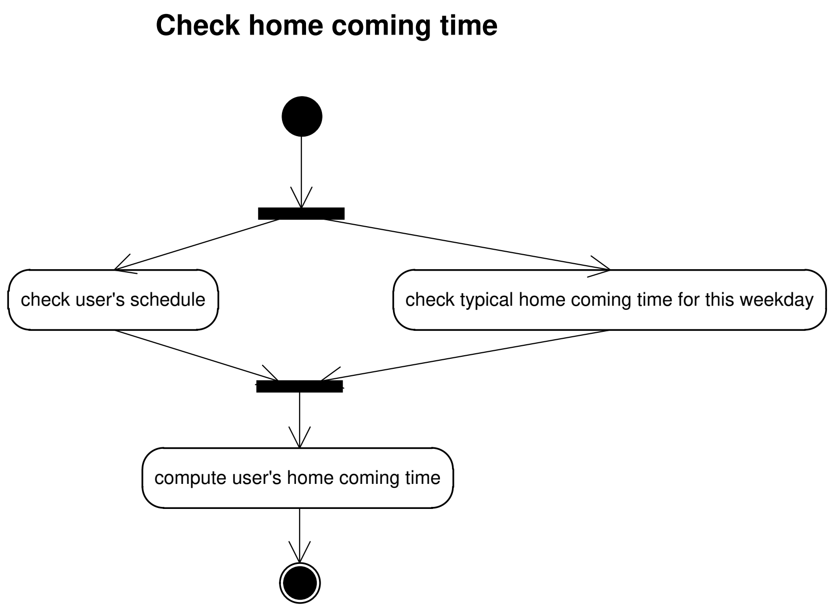

Diagram 32: Check Home Coming Time Activity Diagram

3.2.11.2 Gather & Present Events

This use case describes the potential of the system to store specific events and incidents. This may be a broken washing machine or any other white ware device with a detailed description what kind of damage occurred to easily call a technician and give him a problem report. Furthermore, it could be just some kind of notification for example that a window was closed in the night because it was left open. But additional to reporting of past events the system can also comment actual events. For example, it can state that the back door is open for more than 20 minutes or that a window should be closed to reduce cool down of rooms. Also the system may show the user a short video extract from the door when someone wanted to visit while he was away.

Use Case Summary:

Name	Gather & Present Events
Goal	• Gather events • Present events
Summary	All devices as well as facilities in the house are checked if events occurred. All events are gathered and sorted. According to the user's preferences they are processed and presented to the user.
Actors and Stakeholders	• Windows / Doors • HVAC • Shutters • Audio & Video Devices • White Ware Devices • Appliances • User
Parameters	• Various

Pre condition	-
Post condition	• Events gathered • Events presented

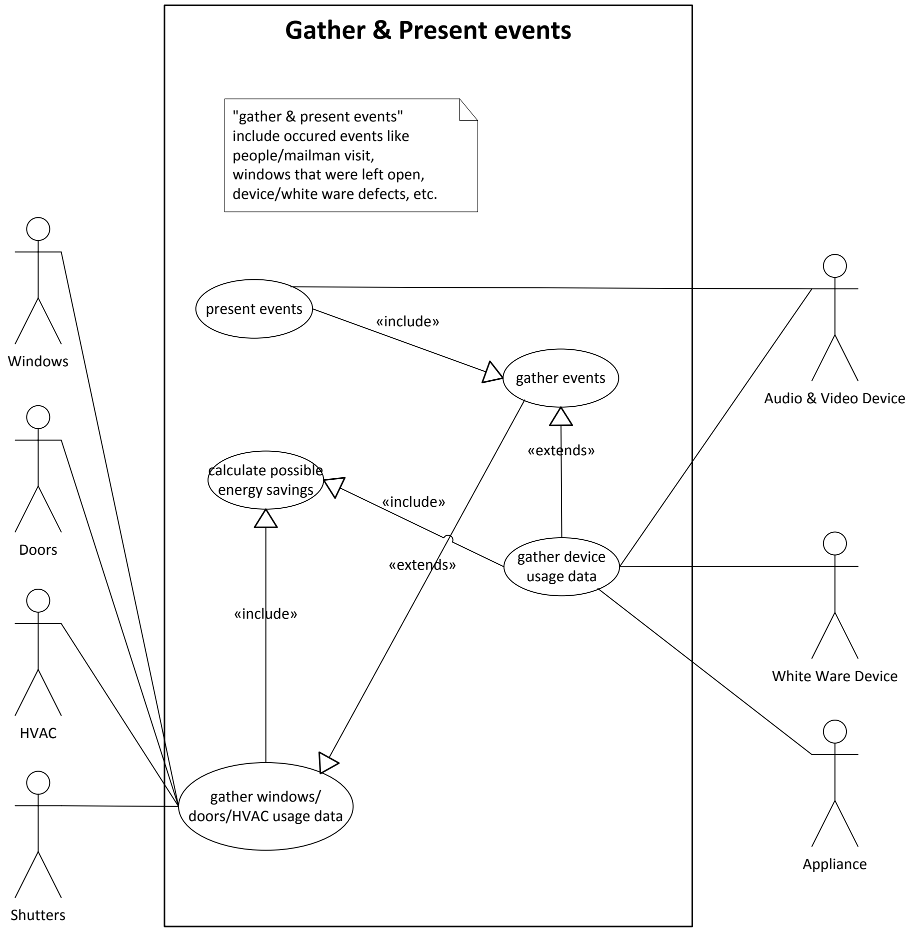

Diagram 33: Gather & Present Events Use Case Diagram

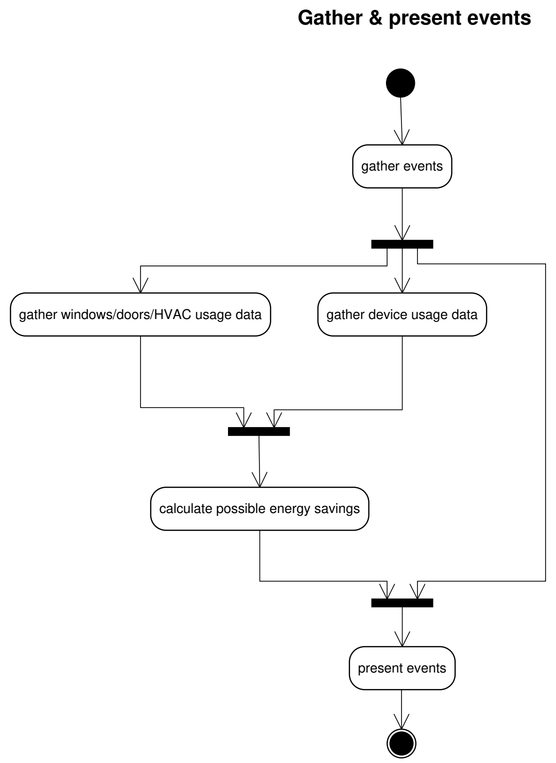

Diagram 34: Gather & Present Events Activity Diagram

4 Conclusion

This thesis gives an introduction and overview in the complex and emerging area of smart homes. While automation is already of common use in factories, offices and commercial buildings, the big breakthrough in the residential area has not taken place yet. Due to the increasing energy demand of private households, home automation – especially supplemented with an advanced artificial intelligence – is a good way to reduce the energy thirst without diminishing people's comfort. In fact, there are a lot of possibilities to increase the comfort of inhabitants even more. Also the huge amount of different control networks that coexist in this sector is taken a look at. A lot of them are used in a specialized operational area and are not suitable for other uses or just cannot compete with others that are more specialized. Currently, there exist two major players – KNX and LON – on the field that cover nearly all topics of building automation and smart homes. They have the longest history of all mentioned networks and have the greatest potential becoming a sole international standard in this sector. Another possibility would be to agree on certain commands and provide standardized interfaces or have a middleware that translates the different instructions.

As it is stated, there are a lot of hurdles that need to be addressed and questions to be answered to reach the private households. Especially interoperability is a big issue that has to be dealt with before consumers make a step towards automating their homes. As long as it is not guaranteed that a new device fits into an existing smart home people will likely wait until this problem is solved. Another important challenge is the sustainability of the house. The smart home is using regenerative energies like photovoltaic or wind energy efficiently and needs low natural resources during its service life. Especially to cut down the operational costs, home automation has high potentials as it is demonstrated later in this chapter. A lot of energy that is wasted currently by e.g. devices that are not switched off or windows that are not closed, can be saved. Also the hardware parts that are used should have a long durability compared to the current life cycle of many electronic consumer products. Another subject that must be dealt with is security and privacy. Due to the fact that a lot of personal data is stored or at least sensed, it has to be assured that it is safe from unauthorized access. Another way to clear the entry hurdle for end users may be extensibility. A basic version of the smart home can provide a set of features that can be extended bit by bit due to the house owner's wishes – in other words the smart home should be a modular system. So the building owner will not have to pay such a great amount of money when building the house and therefore reduce the entry costs. The perfect intelligent home also adapts to the inhabitants in every aspect. This means that it reacts according to the wishes of the user, saves or recognizes his preferences and even presents information the way he likes. Another important challenge is to integrate computers, sensors and actuators into everyday objects. A term that is often used describing this state is pervasive computing. The user should not be aware of the fact that he uses a computer like we know it today. Next to the mentioned ones there are a lot of other concerns like maintainability to name just one of them that need to be addressed before smart homes penetrate and are successful at the end consumer market.

To round the introduction in the smart home topic off a selection on some outstanding projects and smart home model houses is presented. As it can be seen the model homes are often used as laboratories to test new products or are just a kind of show case to present the advantages of some products. Next to the high polished show case houses which are supported by big companies also small houses financed with a low amount of money or private means are emerging. People use currently available products, connect them and make them remotely controllable by inhabitants or a self-made artificial intelligence and achieve interesting and excellent results. These demonstration houses show that it is possible to create and build a smart home with abilities that are described in this thesis. The problem is that such houses are too expensive for the majority of citizens at the moment and the challenges to integrate a set of features or new devices are difficult to overcome in some cases even for members of technical institutes or companies that have skilled personnel.

The main part of this thesis presents the advantages of an intelligent home by means of different use cases situated in all areas of the smart home sector. First four user stories tell typical situations in households and give a glimpse on the potentials in having a smart home. The home takes care of repetitive tasks, turns off unnecessary activated devices, regulates HVAC or reminds and notifies the user about different events. Next to all these aspects that also increase the comfort of the inhabitants, the energy usage is decreased significantly. The use cases mentioned are then categorized in the different scopes of home automation like lighting, HVAC or comfort and described in more detail. Their operational area and ways to implement such a solution are described as well as the goals of them. Additionally, they are represented as UML use case and activity diagrams. The use case diagram's purpose is to give a graphical overview on the functions and which actors are involved during its execution. The activity diagrams then again show the process of the use cases as well as decisions and alternative ways the smart home has to consider. As it can be seen in a lot of activity diagrams, many features that are presented can be achieved without needing a powerful artificial intelligence. Of course, in many cases a perfect solution would involve the tracking of the user's path and position as well as interpreting his actions. The most comfortable way how this can be implemented is by using video cameras because the user does not need to wear any tracking device with him all day and that needs an advanced artificial intelligence. But despite this, an immense energy reduction can be achieved by just using simple rule based algorithms without a lot of branching.

In this last chapter the energy reductions are pointed out that can be obtained by several use cases described in this thesis. Up to now, it is just stated that there is a potential for reducing energy efforts without presenting any data. Here some facts are presented to give the reader an idea of the impact a smart home can have on energy consumption. Some of the data is taken from pilot projects using similar techniques that are described in this thesis and some of the data is calculated with simple formulas. The examples used are based on different use cases that are previously presented in this thesis. It has to be pointed out that these calculations are held pretty simple because taking all relevant factors into account goes beyond the scope of this thesis. For example, there are a lot of different means for heating in Austria like gas, oil, wood, district heating that differ in the carbon dioxide emissions as well as the amount of energy that is needed to heat a square meter living space.

The first step in the calculations is defining the average Austrian household:

Energy Consumption Calculation

The data is taken from Statistic Austria[34], the Austrian statistical department, and the "Projektbericht: Strom und Gastagebuch 2008" [STAT2008].

$$Living\ area = \frac{principal\ residence\ area}{amount\ of\ principal\ residences}$$

$$Living\ area = \frac{299636000\ m^2}{3315347} = 90.378\ \text{m}^2$$

The values of reduction in energy consumption and CO_2 footprint are calculated by the following formulas and base values:

Carbon Footprint Calculation

Additional values for the calculation of the carbon footprint are taken from "Energiesparhaus.at – unabhängige Beratung für Wohnen, Hausbau und Sanierung"[35], an Austrian project powered by experts of many industrial branches.

[34] Statistik Austria, Bundesanstalt Statistik Austria, available on the Internet, URL: http://www.statistik.at/, 2010-10-08

The Carbon footprint caused by heating is roughly calculated by the typically used forms of heating in Austria.

$$Carbon\ footprint\ of\ coal = 0.19\ kg/kWh$$

$$Carbon\ footprint\ of\ gas = 0.28\ kg/kWh$$

$$Carbon\ footprint\ of\ oil = 0.32\ kg/kWh$$

$$Carbon\ footprint\ of\ heating = \frac{coal + gas + oil}{3}$$

$$Carbon\ footprint\ of\ heating = 0{,}2633\ kg\ /kWh$$

Also the average annual energy usage by a household is roughly calculated by adding the typical consumption of six months in summer as well as in winter.

$$Carbon\ footprint\ of\ electricity\ in\ summer = 0.18\ kg/kWh$$

$$Carbon\ footprint\ of\ electricity\ in\ winter = 0.35\ kg/kWh$$

$$Carbon\ footprint\ of\ electrical\ power\ usage = \frac{winter + summer}{2}$$

$$Carbon\ footprint\ of\ electrical\ power\ usage = 0{,}265\ kg/kWh$$

Therefore the following data is representing an average Austrian household. For simplification of the statistic, the price of gas is used for representing the savings in heating:

Average Austrian Household	General data and energy statistics
Living area	90.378 m²
Number of people	2.3
Energy statistics	
Average gas consumption	4175 kWh (2007)
Average energy consumption	4390 kWh (2007)
Average price electrical power [STAT2008]	18 ct/kWh
Average price gas [STAT2008]	~ 6 ct/kWh
Carbon footprint	
Caused by heating	0.2633 kg/kWh
Caused by electrical power consumption	0.265 kg/kWh

The titles of these examples represent a concept already described in a previous chapter.

Use Case	Ensure air quality (automated airing) (3.2.4.1)
Potential Savings	• 2% less heating (to automated 2 point ventilation, no comparison to manual airing available) • ~ 87 KWh less heating • ~ 22.9 kg CO_2 / year • ~ 5.22€

[35] "Energiesparhaus.at", "Energiesparhaus.at - CO_2-Emissionen", available on the Internet, URL: http://www.energiesparhaus.at/fachbegriffe/co2.htm, 2010-03-24

Use Case	Visualization of energy consumption (ECOIS II - 2.5.1)
Potential Savings	• 8.8% less heating • 365.8 KWh less heating • 21.95 € less heating expenditures • 17.8% less electrical power consumption • 781.4 KWh less electrical power consumption • 140.65 € less electricity expenditures • Overall 303,39 kg CO_2 / year

Use Case	Security camera and motion sensors
Potential Savings	• Between 3 and 9 watts power consumption (with 50% activity in 24 hours) • <1 % less electrical power consumption • 13.1 to 39.4KWh less electrical power consumption • 3.45 to 130.37 kg CO_2/year • 2.36 € to 7.09 €

Use Case	Turn off energy consumers
Potential Savings	• Projection on average standby consumption per year • 4.26% less electrical power consumption • 187 KWh less electrical power consumption • 49.55 kg CO_2 / year • 33.66 €

As it can be seen, there is a lot of energy saving potential in applying just a few use cases. The amount of energy saved when having a fully functional smart home is enormous.

An outlook into the future of smart homes is pretty good. The homes of people are equipped with electric appliances and computers more and more. A few years ago it was common that one computer was used for the whole household. Now it is normal that every member of a family has its own computer. Processing power, cameras, sensors and actuators are getting cheaper constantly. Although Moore's Law may not be fulfilled in the future, the possibilities of artificial intelligence will emerge and new areas may be unlocked with it, such as improved awareness of the user's actions or in which context objects in the home are used.

The other side of the coin is already described in the chapter 2.4 – "Current Challenges". The aversion of many people in using a new and generally speaking an unproved technology is rather high. By now equipping a building with home automation devices like they are described in this thesis is technically solvable. The challenging part is to combine the possibilities with a powerful artificial intelligence. Although integrating the parts in a house is increasing a new home's price by a non marginal amount, the house's value is increasing and the operational costs are reduced drastically. Although there are currently a lot of negative aspects that need to be challenged, there is no doubt that smart homes, with abilities similar to those that are described in this thesis, will become more popular in the next years as features will diffuse the market bit by bit.

5 List of Diagrams

6 List of Tables

7 List of Figures

8 List of Literature

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