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EVALUATION OF ESTABLISHED ECO-BUILDINGS IN COMPARISON TO TODAY'S PERFORMANCE CHARACTERISTICS

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Die vorliegende Arbeit befasst sich mit der Analyse des thermischem Komforts und des Energieverbrauchs eines Ökogebäudes. Das Objekt wurde im Jahre 1996 im Hinblick auf Energieeffizienz und Nachhaltigkeit renoviert und sollte nach Fertigstellung ein Vorbild für umweltfreundliches Bauen repräsentieren. Die Analyse basiert auf drei Hauptinteressen.

Eine erste Annäherung an die Evaluierung des thermischen Verhaltens des Gebäudes erfolgte durch die Revision über die Jahre hinweg erstellter Listen von Zählerständen. Darüber hinaus wurde zu Beginn dieser Arbeit ein komplexes Messsystem im Gebäude installiert, das alle wesentlichen Informationen über das thermische Verhalten des Bauwerks und des Innenraumklimas bis dato überliefert. Eine dritte Untersuchung basierte auf der Erstellung von unterschiedlichen Szenarien, die mittels Software für statische Kalkulationen und dynamsiche thermische Simulationen errechnet und verglichen wurden.

Die Resultate aus diesen Untersuchungsmethoden wurden mit den Anforderungen österreichischer Normen von heute und der Zeit der Renovierung verglichen. Somit wurde das Gebäude klassifiziert und die Effizienz der Baumaßnahmen eruiert.

Aus damaliger Sicht erreichte das Bauwerk sein Ziel, die Richtwerte adäquater Normen zu übertreffen. Heute erreicht es mit einem Heizwärmebedarf von 65 $kWh.m^{-2}.a^{-1}$ den mittleren Bereich auf der Energieeffizienzskala. Mittels der unterschiedlichen Anaylsemethoden wurden das thermische Verhalten des Gebäudes und die Auswirkungen auf das Innenraumklima evaluiert. Zusätzlich konnten Verbesserungsvorschläge zur Nutzung der installierten Energiesysteme formuliert werden.

The initial interest for the following work corresponds to thermal performance expectations of an existing eco-building in Austria. The building was renovated in 1996 in order to exceed the energy requirements of that time with the aim to design a precursor of ecological and energy efficient buildings by using natural materials and renewable energy sources.

This work examined the thermal performance of the building. It explored to which extend the building meets thermal performance expectations of the past in comparison to standard requirements of today. The examination included the energy use and the thermal comfort of the building. In addition, the efficiency of the systems installed in order to use renewable energy sources was investigated.

Former noted information of dial counters in the heating system were considered first in order to state the heating demand of the building and the energy provided by the solar thermal system. In the initial phase of this work, a monitoring system was installed in the building to measure actual conditions of energy use and internal climate. This data was used to conclude with the heating demand and the thermal comfort conditions. To put the outcome in relation to standard requirements, a benchmark was set with the generation of energy certificates based on different requirements regarding energy demand of the past and today. In order to detect optimization possibilities to save energy, the building was modeled for simulation purposes. These analyzing methods were compared according to current results of the analysis.

In the context of today's standard requirements, the thermal performance of the building reached middle range classification. The analysis showed potential in order to save energy in the building. The heating demand of 65 $kWh.m^{-2}.a^{-1}$ can be reduced by changing the system's operation which would also improve the thermal comfort in the building. The implementation of systems to use renewable energy sources in a construction that was based on the usage of natural materials showed beneficial results.

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Für Iris

1. INTRODUCTION

Ecological buildings are known as *green buildings* that are designed in order to reduce environmental impact with respect to sustainability (EPA 2013). The concept of sustainability is based on the idea to avoid harms on the environment and to keep it in existence (Environment 2013). Efficient energy use and sustainable building design have to be increased in order to follow this path. (EPA 2013, Environment 2013)

According to a publication of the World Resources Institute (1996) the global energy utilization had ascended to about 70 % between 1971 and 1996. The authors assumed a continuous increase in the next few years. Conceivably due to promotion of the term *energy efficiency* during the last decades, the energy use increased to about 34 % between 1993 and 2010. (World Resources Institute 1996)

However, the building sector still covers 40 % of the world's energy consumption (IEA 2013). In respect to energy efficiency, sustainability, and ecological treatment, the field of building construction has substantial influences on global energy savings. Enormous efforts and developments towards the usage of renewable energies in buildings have been achieved. As a result, various possibilities of applications to use renewable energy sources in a building were found.

The subsequent work reports on the topic of sustainable building renovation and the use of renewable energy sources. An eco-building was chosen to analyze energy use, thermal performance, and internal climatic conditions. The building was mainly constructed by using ecological materials and planned with respect on sustainability. The energy used in the building was aimed to be generated by systems using renewable energy sources. A target was to create a model for environmental friendly construction by creating a low energy eco-building.

2. MOTIVATION AND BACKGROUND

2.1 Motivation

Thermal performance analysis of already long time ago established and towards energy efficiency renovated buildings yields several benefits. It informs about the energy demand, both thermal and electrical. Moreover, it can display possibilities to use renewable energies effectively or detect options to improve the thermal performance of the refurbishment.

The development of devices to convert and use renewable energy sources during the last decades offers various advantages today. Energy generated by hydropower, wind, biomass, waste, and solar or geothermal energy are just a few examples to substitute fossil fuels (Al-Hallaj and Kiszynski 2011; Planetseed 2013) in order to reduce harms on the environment.

Recent studies depict an energy consumption of 1089 PJ in Austria in the year 2008 (UBA 2013). Compared to 1990 the amount has increased to about 42 %. Besides the transport and industry sectors, the biggest part is consumed by private households amounting to 25 % of the final energy use (UBA 2013). Beneficially, the energy required can be generated by renewable energy sources to a certain extent, when adequate devices had been installed in a building. In Austria, almost 27 % of the overall energy demand has already been replaced by energy generated with renewable sources (UBA 2013). Advantages and potentials of natural energy sources used in a building are to be discussed in this context.

Hence, the necessity to analyze formerly renovated buildings according to energy efficiency rises. An important aspect is to measure and analyze the performance of a building that was renovated years ago based on former energy standards and to compare the results to today's requirements. The question is how did the building perform right after the renovation and today, years or decades later? Did the requirements of standards change during the building's life cycle? Therefore, the efficiency of the systems installed to use renewable energies is of great interest. Is the efficiency measurable and to what extent? Are there impacts on the user's comfort to be expected?

A benefit of pursuing the proposed research question could be an inspirational teaching aid for future renovation plans. According to the results, methods to implement devices to use renewable energy sources can be followed or improved. In addition, it shows benefits of an ecologic and environmental friendly renovation. Methods to analyze the building's performance are established.

2.2 Background

2.2.1 Previous Research Activities

Recently the rate of renovating buildings towards energy efficiency with regard to implementing renewable energy usage increased (EERE 2001). This development took several decades though. In order to plan buildings towards sustainability all over the globe, numerous researches have been done. In addition, laws and guidelines have been put forward. A unique standard is under development by ISO (2013) in order to simplify the planning process and construction of a sustainable building. Standards are important to determine limits of energy use and guiding values. However, the actual use of a building has to be examined, too, in order to classify the building in a certain range. In addition, improvement possibilities might be found with a comparison of actual values, thermal performance, and comparison to actual standards as evaluated in this present work.

Several existing buildings have already implemented different systems to use renewable energies. The solar house (Sonnenhaus) in Germany represents a building using solar energy (Sonnenhaus 2013), for instance. In order to install these systems in numerous buildings, the effective work and advantages have to be verified. As a consequence, renewable energy systems could be applied to an increasing number of refurbishments and new planned buildings.

The aforementioned example of the solar house institute was founded in 2004. Their concept was to plan buildings based on solar thermal support. Criteria for solar houses were: low U-values, reduced primary energy demand (max. 15 $kWh.m^{-2}.a^{-1}$), high quality insulation, etc. The main principle was to cover the energy demand by solar support of at least 50 %. Additional required heating should use renewable energy sources. In 2004 they counted around 30 solar houses in Germany. Six Years later, the number increased to 500! (Sonnenhaus Institut 2013)

A solar house is stated as an efficient step towards the use of renewable energies in a building. However, these buildings were constructed during the last decade. What about buildings, that were refurbished earlier, e.g. in the late 1990ies? Could the former existing technology also reach this level of resource sparing and energy use reduction? This research treats the use of solar energy in principle. The project handled in the following work considers the overall use of renewable energy sources and economic construction.

Buratti et al. (2012) analyzed the thermal comfort conditions and the energetic performance of a non-residential building by simulation efforts. The model has been calibrated by short term measurements of indoor thermal conditions. The authors concluded with thermal comfort and energy saving potentials for this case study. East orientated windows cause the most comfortable conditions for occupants, whereas south exposed windows result in highest discomfort. In addition, the energetic analysis showed a reduction of energy use for heating by changing the glazing to windows with low-e coating and sunlight control film.

The following contribution reports renovation efforts towards energy efficiency and thermal performance analysis of a building refurbished in 1996 by using different evaluation methods.

2.2.2 Standards and Guidelines - Development

Standards in Austria

> *"Norms are qualified rules of the game, developed by dedicated experts, interest communities and people concerned together in order to simplify everyday life.",*

announced DDr. E. Stampfl-Blaha, vice director of Austrian Standards Institute (2012). Currently, the number of standards in Austria counts more than 22 000 norms (Austrian Standards Institute 2012). The aim is to formulate precise rules and state guiding values for planning purposes. Among numerous other topics the energy efficiency of buildings is also considered.
Ongoing progress in technology and changes of material characteristics require an adaptation in the according standards. Therefore, updated versions of guidelines are published permanently. To get an overview of the basic regulation used in this work, the genesis of the Austrian energy standard will be summarized briefly, based on a study of the Federal Office for Energy (Bundesamt für Energie) in Bern, Switzerland (Riederer et al. 2005).

Chronologic Development

Parliaments of each Austrian state develop their own regulations for any type of building. There is no national law for energy standards in the building sector. The funding for residential buildings in Austria (Wohnbauförderung WBF) establishes further rules concerning energy efficient constructions besides these regulations. In Vorarlberg, they started to develop rules for energy efficient planning together with the WBF in the 1980s. Subsequently, the other states followed this arrangement. Primarily, the building regulations are valid for new constructions. After the oil crisis, they were extended with aspects regarding energy use. In article 15a of the Austrian federal constitution, a commitment from 1980 obliges all states to include minimal energetic requirements in their building regulations. For the first time in 1995 the next intensification of energy standards was strengthened. Based on a European direction, it was required to reduce U-values, and to introduce energy classification figures and energy certificates for buildings. The guidelines of the Austrian Institute of Structural Engineering (Österreichisches Institut für Bautechnik OIB) rule at first instance. Standards as ÖNORM act as secondary regulation. (Riederer et al. 2005)

OIB and the Energy Certificate

OIB was founded in 1993 and assumed responsibility to develop standards in the building sector for the European Union on behalf of Austria. Until 1999, the institute generated a guideline to compute energy classification values, based on a building's heating demand. These principles are depicted in the OIB-guideline 6 *Energy saving and thermal insulation* (OIB RL6 2011) and based on a list of ÖNORMs and technical regulations (OIB 2012). On April 20th 2012, a law demanding an energy certificate for all buildings, which should be committed to a new owner or user (Energieausweis-Vorlage-Gesetz), was published (Bgbl.RÖ 2012). Accordingly, guidelines had been developed in order to standardize the generation of energy certificates. OIB developed a guidance document about the specific energy performance of buildings (OIB Leitfaden RL6 2011). It handles all relevant steps in the generation of an energy certificate. These are namely parameters according to climate, user profiles, zoning of the building, energy demand, building geometry, building installations, and building physics.

The main indicator to classify a building regarding its energetic performance is represented by the heating demand. It is related to the local climate and calculated per square meter heated gross area in one year [$kWh.m^{-2}.a^{-1}$]. The guiding values in OIB RL6 (2011) were distinguished for either heated residential or non-residential and new planned or renovated constructions. In 2011 the latest version of this regulation was published. Table 1 resumes the maximum values of allowed heating demand per square meter and year and building type. OIB guidelines are based on Austrian standards that are listed in Table 2.

Table 1. Maximum permitted heating demand [$kWh.m^{-2}.a^{-1}$] of renovated buildings pursuant OIB RL 6 (2011) per year.

Year	Residential buildings	Non-residential buildings
2007	102	33
2010	88	30

Table 2. Austrian standards cited in OIB guidelines (OIB 2012).

ÖNORM	Title
B 1800	Ermittlung von Flächen und Rauminhalten von Bauwerken
B 8110-2	Wärmeschutz im Hochbau – Teil 2: Wasserdampfdiffusion und Kondensationsschutz
B 8110-3	Wärmeschutz im Hochbau – Teil 3: Wärmespeicherung und Sonneneinflüsse
B 8110-4	Wärmeschutz im Hochbau – Betriebswirtschaftliche Optimierung des Wärmeschutzes
B 8110-5	Wärmeschutz im Hochbau – Teil 5: Klimamodell und Nutzungsprofile
B 8110-6	Wärmeschutz im Hochbau – Teil 6: Grundlagen und Nachweisverfahren – Heizwärmebedarf und Kühlbedarf
EN ISO 13790	Energieeffizienz von Gebäuden - Berechnung des Energiebedarfs für Heizung und Kühlung
EN 13829	Wärmetechnisches Verhalten von Gebäuden – Bestimmung der Luftdurchlässigkeit von Gebäuden – Differenzdruckverfahren (ISO 9972:1996, modifiziert)
H 5056	Gesamtenergieeffizienz von Gebäuden – HeiztechnikEnergiebedarf
H 5057	Gesamtenergieeffizienz von Gebäuden – Raumlufttechnikenergiebedarf für Wohn- und Nicht-Wohngebäude
H 5058	Gesamtenergieeffizienz von Gebäuden – Kühlenergiebedarf
H 5059	Gesamtenergieeffizienz von Gebäuden – Beleuchtungsenergiebedarf
M 7140	Betriebswirtschaftliche Vergleichsrechnung für Energiesysteme nach der erweiterten Annuitätenmethode – Begriffsbestimmungen, Rechenverfahren

2.2.3 The Case Study Building: National Park Academy (NAT)

One paradigm of eco-houses has been designed in Petronell, Lower Austria, named the National Park Academy of the Vienna Museum of Natural History (referred to, hereafter, as NAT). The owner aimed to build a model of sustainable construction with pioneering role for energy efficient eco-buildings after its renovation.

History of NAT

In the past, the building's function was combined residential and commercial. A small shop next to the living space offered everyday needs. The thick brick exterior walls were covered with a thatched roof. Figure 1 shows NAT at the time around 1950.

Figure 1. NAT in the 1950ies (Source: NAT administration).

Renovation Aims

In 1996, NAT was renovated with the target to surpass the minimum requirements of Austrian standards at that time concerning thermal performance characteristics. Moreover, the use of renewable energy sources was planned. The issue was to extend an old building by keeping the original foundation walls, but to augment a construction based on ecological principles. The aim was an energy efficient, sustainable building. Environmental friendly construction materials from the near vicinity were preferred. High quality insulation ought to reduce the energy needs. Solar energy and biomass should provide heat and electricity at NAT. In addition, the grey water was to be recycled and rain water to be used. The basis of the renovation was an attempt to set up a record in the so-called *ecological pentathlon* within the categories of energy, water, materials, climate, and landscape (Lötsch 1999). The following aims had been pursued in respect to climate and landscape issues:

- Carbon neutrality
- Adaptation to the local climate
- Independence of disposal sites
- Recycling possibilities of the building's elements
- Design customized to location to fulfill cultural landscape challenges
- Pond biotope construction

Architect Mag. Arch. Ing. H. Deubner from the architectural office *Atelier Für Naturnahes Bauen* was responsible for the redesign of NAT. Pannonian style was the main influencing factor in the design in response to contiguous buildings. Figure 2 and 3 show NAT before the renovation and Figure 4 and 5 illustrate the building after the refurbishment in 1996.


Figure 2 and 3. NAT before the renovation in 1994 (Source: NAT administration).


Figure 4 and 5. NAT after the renovation in 1996 (Source: NAT administration).

Construction Materials and U-values

Arcades open the building towards the south. The aim was to exclude the high standing sunrays in summer. Though, desired low standing rays of the winter sun are able to pass into the building and warm it.

In order to reach low U-values, walls have been insulated with 14 cm cork panels. Roofs contain either cork as granulate or flax between the chevrons. The thatched roof has been replaced by roof tiles. New built dormers in the first floor have been insulated with cork, too. Table 3 lists resulting U-values of the construction in comparison to requirements of standards at different times.

Note that NAT’s construction elements show significantly lower U-values in most cases than required at the time of its construction.

Table 3. Chronology of required U-values [$W.m^{-2}.K^{-1}$] for different building elements pursuant OIB RL 6 (2011) and actual U-values of NAT's construction.

	cellar ceiling	ceiling upper floor	external wall	roof	window	external doors
since 1883	1.43	1.60	1.82	2.70	2.20	2.30
before 1900	1.25	0.75	1.55	1.30	2.50	2.50
since 1900	1.20	1.20	2.00	0.60	2.50	2.50
since 1923	1.43	0.90	1.63	1.70	2.30	2.30
since 1945	1.95	1.35	1.75	1.30	2.50	2.50
since 1950	1.22	0.63	1.28	0.96	2.50	2.30
since 1960	0.90	0.52	1.52	0.70	2.50	2.30
since 1969	0.63	0.48	0.80	0.55	2.50	2.30
since 1976	0.56	0.44	0.60	0.35	2.50	2.30
since 1982	0.80	0.30	0.70	0.30	2.50	2.50
since 1988	0.70	0.25	0.50	0.25	2.50	2.50
NAT	0.29	0.29	0.19-0.25	0.17/ 0.41	1.25	1.30
since 1996	0.50	0.22	0.40	0.22	1.80	1.80
since 2007	0.40	0.40	0.35	0.20	1.40	1.70
since 2011	0.40	0.40	0.35	0.20	1.40	1.70

Floor Plan Organization

NAT has been planned with a net useful area of 336 m^2 on a parcel of 1085 m^2. The ancient cellar has been maintained (110 m^2), the ground floor extended (240 m^2), and a first floor built-on (96 m^2). The first floor can be extended by the loft of the western ground floor. NAT offers a place for excursion, teaching, research, and residential purposes since the refurbishment in 1996. Guiding values cited in this work focus on residential and office building characteristics.

Figure 6 and 7 show the floor plans of NAT.

Two seminar rooms are situated in the ground floor on the east and the west side with a capacity of 40 individuals each. The office of NAT's guidance is located adjacent to the eastern class room. The storage room, the bathroom, and the staircase to the cellar are placed in the northern part of the ground floor. A winter garden is situated in the south between the office and the eastern seminar room. The kitchen in the western part of the building is orientated to the south east.

Bedrooms for pupils are designated on the first floor, facing either the north or the south. The eastern end closes the corridor with a balcony. A group bedroom is placed in the north western corner of the building.

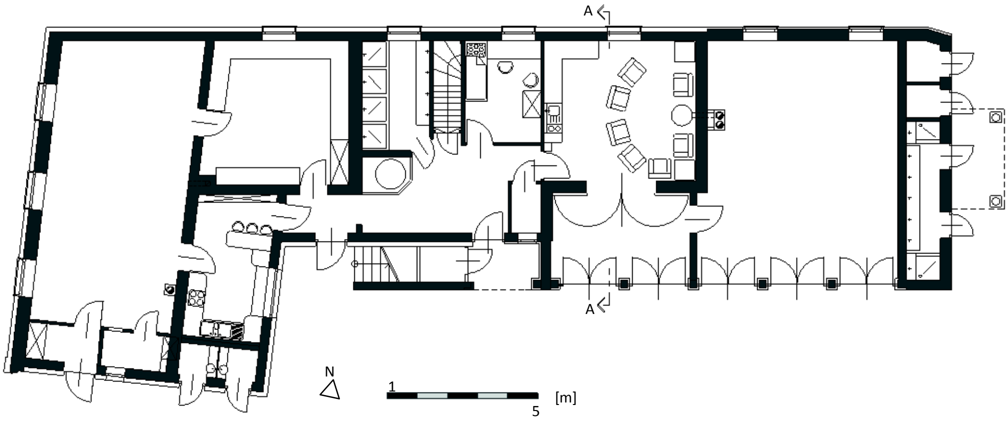

Figure 6. Floor plan ground floor of NAT (based on H. Deubner).

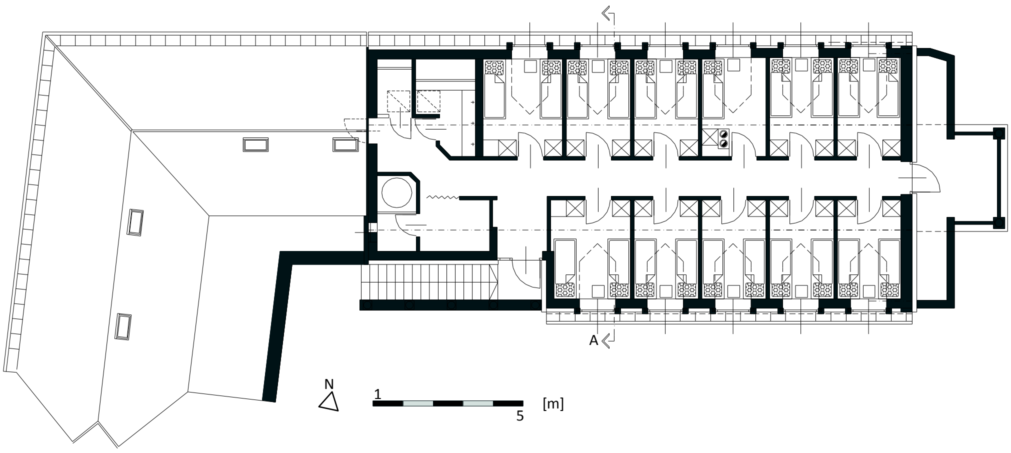

Figure 7. Floor plan first floor of NAT (based on H. Deubner).

Figure 8 illustrates a section of NAT through the extended part with dormers and the old cellar. Figure 9 shows a photograph of NAT with the extension from aerial view.

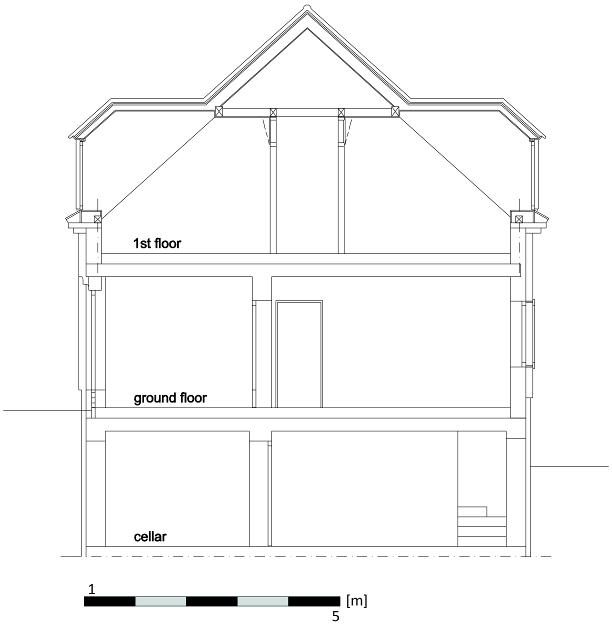

Figure 8. Section A-A of NAT after the renovation (based on H. Deubner).

Figure 9. Aerial view on NAT after the renovation (Source: NAT administration).

Heating System

A solar thermal system provides heat and domestic hot water for NAT. 48 m^2 of solar thermal collectors have been installed on its roof (Figure 9) to convert solar radiation into thermal energy. The energy gained by the solar panels is transported by a circulating liquid, which passes two heat exchangers before it reaches a storage tank. In case of more energy is produced than needed by the occupants, the heat is stored in a reservoir. Table 4 informs about its dimensions.

Table 4. Characteristics of the storage tank at NAT.

Diameter	Height	Content	Warm water boiler
100 cm	4000 cm	3000 l	+ 500 l

Water for the heating system is collected in the outer part of the tank (3000 liters). The core contains a boiler with water for sanitary use (500 liters). Water heated by solar radiation reaching the panels is stored in the upper part. The colder return flow (25°C) of the circulating liquid is stocked at the bottom of the tank. To support the temperature layers in the tank, it was dimensioned with a width of only one meter, but with a height of four meters. It was placed in the center of the building to use the warm radiation of the steal body in the building. In order to use the heat flow in an optimized manner, a low temperature floor heating system (25 - 30°C) has been installed with two circles: one in the ground floor, one in the first floor.

In case of low solar radiation, the heating system is supported by a pellet burner. This heat is transported by another water circle and flows in the upper part of the storage tank. The heating demand has been assumed to reach 47 $kWh.m^{-2}$ (Lötsch 1999). Its peak power reaches 25 kilowatt. Habitually, pellets are used for the firing, but any wooden non-fossil fuels are suitable. An adjacent room of 20 cubic meters in the cellar stores the pellets. They are transported to the burner via a screw-conveyor. The feeding works automatically. With this system, the aim of using CO_2 - neutral, renewable energy sources from the near vicinity is achieved.

Solar thermal systems for heating and warm water supply in combination with a wood pellets burner constitute an optimal environmentally friendly solution

(Pistohl 2007b). In respect to ecological construction, this system has been installed at NAT after the renovation of the building. This was a novelty in Austria at that time.

During the summer period, the pellets burner is usually switched off, since the warm water in the building is provided by the solar thermal system. Generally, the storage tank should cover the heating load partly in the transition time from the warm to the cold season (Pistohl 2007b, Lötsch 1999).

Electricity

Around 77 m^2 of NAT's premises have been covered with photovoltaic panels in order to generate electricity. This area has been divided into three circles. One section of around 29 m^2 generates electricity used by NAT itself in case of demand. The surplus is fed into the local public grid. In case of low solar radiation this grid provides NAT with electricity.

In times of optimal conditions, the installation should reach a maximum power of 3.6 kWp, as stated by the implementing company. All three circles together are assumed to reach a maximum of 10.0 kWp.

2.3 Research Objectives

NAT aimed to incorporate a leading role in the field of sustainability concerning its building construction and energy needs. Ecology was the guiding factor during the planning process. The energy use of NAT after the renovation was targeted to be lower than the guidelines required at that time.

With the commissioning of NAT, the administration had planned to document and evaluate its thermal performance. The idea was to examine the building critically in order to improve performance and equipment in sustainable, technical, and economic aspects.

By the start of this research, the thermal performance of NAT was not stated scientifically. Information about energy use and heating demand was gathered by NAT's administration temporally, but not ongoing.

In respect to continuously changing guidelines and recent research efforts in energy efficient planning, it is of current interest to state the thermal performance of NAT 16 years after the renovation. Results may be an informing aid and guiding support for other projects. NAT can be seen as a case study with enormous research potential. In this work, the following questions have been considered.

1. Does the building (NAT) meet thermal performance expectations according to standard requirements?

Thermal performance expectations consider the energy used at NAT and heat fluctuation in the building in relation to requirements of standards. An overview about building classification according to the heating demand is stated in various standards and guidelines, e.g. ÖNORM B 8110-5 (2010) or OIB RL 6 (2011).

Method:

In order to analyse NAT's heating demand and classify the building, different methods have been used. A benchmark has been set with the generation of an energy certificate. It has been created according to changing requirements of different times of NAT's life cycle. In addition, the influence of different parameters on the heating demand was examined by creating different scenarios.

Based on historical information and monitored data the actual heating demand was calculated. In this context, the standard requirements and actual demands were compared. The results were used to classify the building.

2. Does the energy system of NAT, which is based in part on renewable energy sources, operate efficiently?

As NAT represents an eco-building, the use of renewable energy sources was of great importance. The systems have to be chosen according to local climate conditions and availability.

Method:

The outdoor air temperature and solar radiation have been analyzed based on measured data. In addition, the monitoring system provides information on the energy used by the pellet furnace, the energy generated by the solar collectors, and the internal climatic conditions. The relation between energy input and output has been examined. Furthermore, the amount of heat provided by each system has been stated and the calibration of the systems has been analyzed. Based on these findings, different settings have been suggested in order to improve the efficiency of the systems.

3. Which parameters have the biggest influence on the building's thermal performance?

External and internal conditions influence the heating demand of a building. In order to analyze the building's thermal performance and to state improvement potentials, the most influential parameters regarding energy use have to be determined.

Method:

Scenarios have been developed to examine the impact of various input parameters on the results of the thermal simulation and the energy certificate.

4. Does the building meet thermal comfort requirements?

Thermal comfort requirements define acceptable internal climate regarding temperature and relative humidity. Standard conditions are described in the ASHRAE standard 55 (ASHRAE 2004).

Method:

To determine thermal comfort conditions, comfort charts have been created based on measurements. In addition, the infiltration rate has been calculated using the carbon dioxide concentration data recorded in different zones. The calibrated model has been used to simulate a period in summer in order to examine indoor climatic conditions during the hot season.

5. Monitoring and simulation: In which way support these methods the thermal performance analysis of NAT?

An ongoing monitoring system delivers data about real conditions considering thermal comfort, energy demand, and occupancy behavior. In contrast, a simulation model was created in order to predict the energy demand of a building in most cases. However, it was calibrated with measured data in order to simulate the model with optimized input settings, too. In this study, the actual heating demand and optimization possibilities had to be detected.

Method:

Working process, results, and analysis details have provided a conclusion about all techniques used. Data recorded by the monitoring system has been used in order to state the actual heating demand and discover potentials to use less energy. For the simulation process, different use cases have been created with the same target. In addition, most influential input parameters have been determined with a sensitivity analysis after the simulation. The potential of each method to find desired outputs has been proven.

3. METHODOLOGY

The established eco-building NAT was evaluated in different procedural steps. Energy use, internal environment, weather influences, and electricity provision were considered. Along the way results were compared to today's performance characteristics defined in standards.

A first overview of the energy use and solar thermal energy support was delivered by so-called historical data: meter readings noted by NAT's administration during the period 2006 and 2011 were analyzed and opposed to according weather data.

The monitoring system provided information about the current state of NAT's thermal performance, energy use, internal conditions, and outdoor climate. Thermal comfort was analyzed in consideration of occupancy, internal temperature, and relative humidity data. Air quality was investigated by measurements of carbon dioxide concentration and infiltration rate. In addition, the efficiency of the installed energy systems was examined.

A benchmark was set with an energy certificate. According to requirements of Austrian standards, the heating demand of several cases before and after the renovation was calculated. NAT has been classified in relation to other buildings throughout different periods in time.

Conclusively, a simulation model was calibrated by gathered information. After the adjustment by standard requirements, the measured specifications were used as input parameters for the simulation of NAT's thermal performance. Subsequently, different scenarios were developed to discover energy saving potentials of NAT. A sensitivity analysis informed about the most influential factors on the heating demand.

3.1 Historical Data Analysis

A first overview of NAT's energy use provided the analysis of historical data. NAT's administration had been collecting information about the energy use of the building for several years. They took care about the refilling of the storage room with pellets and noted the ordered amount per year. A heat meter counted the energy provided by the pellet furnace. Another one informed about the energy gained by the solar thermal collectors. In average once a week, both meter readings were listed manually by the administration. These handwritten lists showed an overview of the pellets consumption and solar gains. They were available for several recent years and digitalized to proceed with further calculations of the heating demand and solar energy income. Thus, energy use, solar gains, and heating demand were calculated. This information has been related to weather information in order to get a better understanding of the energy use.

3.1.1 Energy Provision by Burning Pellets

Based on information provided by NAT, the yearly amount of pellets required for heating was stated. The refilling times and amounts were read from ordering bills available from 2006 to 2012.
The earliest information of the counter reading was dated in November 2006 and lasted until March 2012. This data was analyzed regarding monthly and yearly energy use. Furthermore, the energy demand per square meter and year was calculated.

3.1.2 Energy Supply by Solar Thermal Collector System

Energy Generation by Solar Thermal Collectors

Information about solar gains was available starting with October 2006. Meter readings had been noted until April 2007 and were continued again in January

2011 until March 2012. Likewise, this data was examined in order to state the monthly amount of solar gains for each year. This information was put in relation to solar irradiance of according years. Therefore, a ZAMG weather database of Seibersdorf, near to NAT, was used. Conclusively, the relation of radiation and energy generated by the system was analyzed.

Overall Energy Demand

The overall demand of thermal energy at NAT is the sum of heat provided by the pellet furnace and the energy generated by the solar thermal collector system. The energy use for heating and warm water supply was stated for each month as an average value. Furthermore, this information was represented for one instancing year. The monthly amounts of heat provided by the pellet furnace and the produced energy by the solar thermal system were compared. Finally, the heating demand per month and year was calculated.

Thermal Energy Demand Covered by Solar Thermal Collector System

In order to answer the question, to which extend the solar collectors worked efficiently, the energy use of the entire heating system had to be considered. The entire heating demand was calculated before. The amount of energy produced by the solar thermal system was listed. Conclusively, the ratio of these values informed about the energy that the solar thermal system could cover in a certain period. The demand of thermal energy at NAT covered by the solar collectors has been stated for the year 2011.

3.1.3 Weather Data

To discover potential influences on heating behavior and solar gains, climatic conditions were analyzed. ZAMG, an Austrian institution for measuring and storing weather data, provided information of the last decades. The location of NAT was not recorded in their database. Instead, data from the nearest proximate measuring point was used. About 40 km south-west of the case study building the next weather station was located, in a village named Seibersdorf. The climatic conditions of these two spots were assumed to be commensurable due to the geographic distance. Therefore the climatic changes have not been notably high in this case.

Hourly values of wind direction, relative humidity, global radiation, precipitation sum, outdoor air temperature, and wind speed were received from 1985 until 2012. According to the period of noted data of NAT's administration about thermal energy, weather information of the years 2006, 2007, 2010, and 2011 was analyzed. These measurements were generated for each day and month. With the target to evaluate heating demand and solar gains, the evaluation of weather influences considered outdoor air temperature and global radiation.

Outdoor Air Temperature

The outdoor air temperature was evaluated with regard to monthly mean values for the relevant years 2006, 2007, 2010, and 2011. In addition, the average temperature of each month was calculated to mark a temperature trend. Mean values of each year were determined. Thus, the outdoor air temperature measurements of these years were compared to the heating demand and analyzed towards influences on the energy use at NAT.

Solar Radiation

The measurements of global radiation at Seibersdorf were analyzed according to the outdoor air temperature data. Monthly mean values were generated for the according period.

Increased values of global radiation were assumed to be reached in the summer months, indicated by a rise of external temperatures. Thus, the incoming solar radiation was compared to the outdoor air temperature trend. Increased potential for solar gains was aimed to be detected with this analysis.

3.2 Monitoring Process

The evaluation of NAT's current thermal performance characteristics required actual information about the building's energy use. Current state analysis of energy needs was established in order to compare today's results to standard requirements and historic data. Therefore, an ongoing monitoring system was installed at NAT in 2012. Thus, information about the initial situation was received. This system was configured to gather relevant information about heating demand, system efficiency, and thermal comfort. In addition, external climatic conditions were recorded by a weather station.

Measuring Devices

The monitoring system installed consists of measuring devices listed in Table 5. Technical data is available in the appendix.

Table 5. Characteristics of measuring devices installed at NAT.

Sensor type	Unit	Information	Device
CO_2	ppm	Carbon dioxide concentration	Thermokon SR04 CO2
Contact	boolean	Opening/closing of windows/doors	Thermokon SRW01
Electricity meter	Wh	Electricity use	Thermokon SR-MI-HS
Illuminance	lx	Light levels	Thermokon SR-MDS Solar
Occupancy	boolean	Presence of people	Thermokon SR-MDS Solar
Compact heat meter	Wh	Heating energy	EWT Ray
Relative humidity	%	Relative humidity in a specific location	Thermokon SR04 CO2
Compact heat meter	MWh	Solar energy	EWT Scylar Int 8
Temperature	°C	Indoor air temperature of a certain area	Thermokon SR04 CO2
Flow meter	$l.h^{-1}$	Water usage	EWT Aquarius

Figure 10 shows a device of Thermokon Sensortechnik GmbH (2012) that measures carbon dioxide concentration, internal temperature, and relative humidity. These sensors were mounted at a height of about one meter in each zone, e.g. seminar room east (Figure 11). They needed to be plugged to an electrical outlet.

Figure 10. Thermokon SR04 CO2.

Figure 11. Thermokon SR04 CO2 in seminar room east at NAT.

Information about occupancy was measured by Thermokon SR-MDS Solar (Thermokon 2012, Figure 12, 13). Data was delivered when movement occurred in the transmitting range of around 30 m without obstacles. The energy used to run the sensor was generated by solar cells included in the device.

Figure 12. Thermokon SR-MDS Solar.

Figure 13. Thermokon SR-MDS Solar in seminar room west.

Heat provided by the pellet furnace was measured by EWT Ray (Diehl 2012, Figure 14). It recorded the energy in the flow rate within a temperature range from 5 to 90 °C with a nominal pressure of 16 bar. Its implementation in the pellet furnace system is pictured in Figure 15.

Thermal energy generated by the solar collectors was metered by EWT Scylar Int 8 (Diehl 2012, Figure 16). It was mounted next to the storage tank (Figure 17) to measure energy, power, volume, flow rate, and temperature of the circulating liquid in the system.

To measure the amount of domestic hot water used at NAT, a metering device of EWT Aquarius (Diehl 2012) was installed in the system (Figure 18 and 19). It measured water flow from 12 to 31 liters per hour up to a temperature of maximum 90 °C with a nominal power of 16 bars.

Figure 14. EWT Ray heat meter.

Figure 15. EWT Ray heat meter installed at pellet furnace.

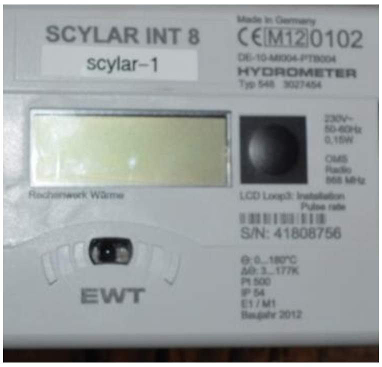

Figure 16. EWT Scylar Int 8.

Figure17. EWT Scylar Int 8 mounted at the storage tank.

Figure 18. EWT Aquarius water meter.

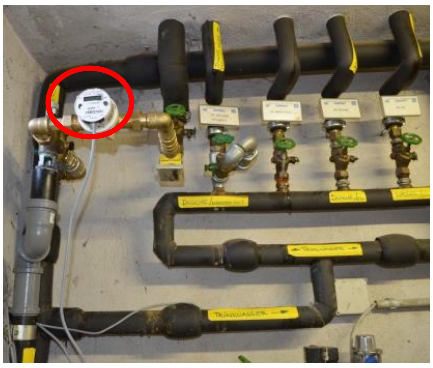

Figure 19. EWT Aquarius water meter in the system.

Figure 20. Thermokon SR-MI-HS.

Figure 21. Thermokon SR-MI-HS installed in the fuse box of NAT.

Zoning

Thermal comfort requirements and energy needs vary due to different spatial use. Thus, NAT was divided in different zones, whereas one zone represents equal internal conditions. These areas were equipped with measuring devices to record internal temperature, relative humidity and carbon dioxide concentration (referred to, hereafter, as TRC). They were placed in the seminar rooms, the kitchen, the corridor, the office, and the bedroom in the ground floor. Occupancy was noted accordingly (referred to, hereafter, as Occ). Table 6 lists different zones at NAT with room function and installed measuring devices. These are displayed in Figure 22 and 23.

Table 6. Zones and installed sensor types at NAT according to room function.

Zone	Room function	Sensor type
1	Seminarroom East	Temperature, relative humidity, CO_2 concentration; Occupancy
2	Office North	Temperature, relative humidity, CO_2 concentration; Occupancy
3	Corridor	Temperature, relative humidity, CO_2 concentration
4	Bedroom Ground Floor	Temperature, relative humidity, CO_2 concentration; Occupancy
5	Kitchen	Temperature, relative humidity, CO_2 concentration; Occupancy
6	Seminar Room West	Temperature, relative humidity, CO_2 concentration; Occupancy
7	Bedroom Group First Floor	Temperature, relative humidity, CO_2 concentration; Occupancy
8	Roof Seminar Room West	Temperature, relative humidity, CO_2 concentration
9	Bedroom First Floor	Temperature, relative humidity, CO_2 concentration

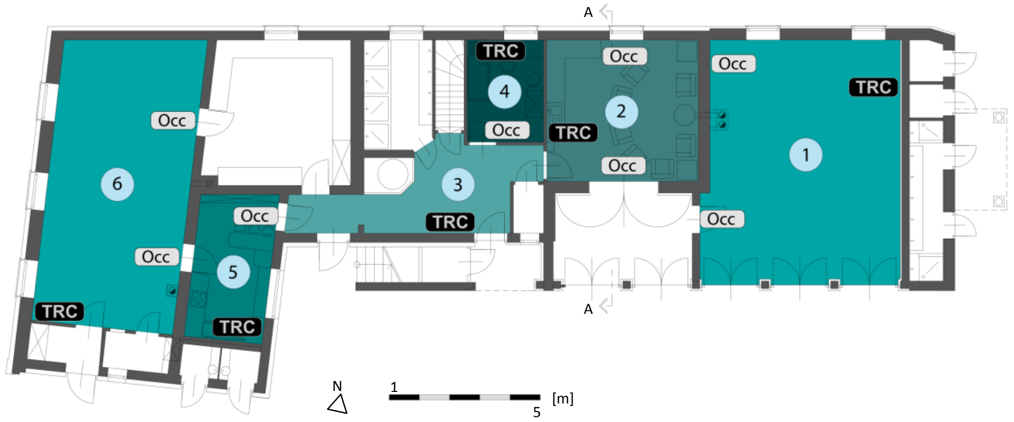

Figure 22. Sensor placement at NAT ground floor.

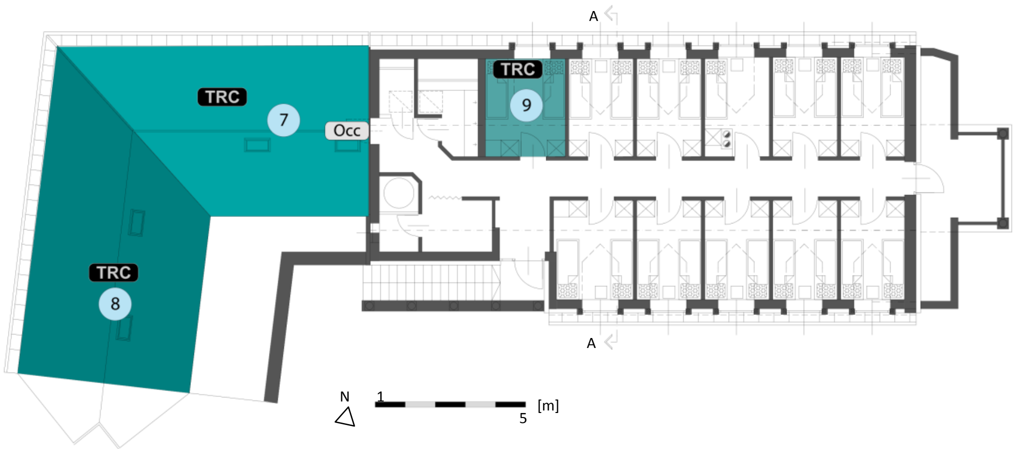

Figure 23. Sensor placement at NAT first floor.

Data Delivery

Past the careful choice and installation of sensors, the information input to the devices had to be collected and stored in a practical and useful manner. R. Zach (2012) developed a tool specialized on monitoring building, storing, and querying data, called MOST. The recorded data is sent from the sensors to a database. With the use of this tool, the information can be interrogated individually at any time.

M. Schuß (2013) has created a webpage in order to visualize the monitored data. Different categories, for instance *power*, *thermal comfort*, *weather*, and *actual values*, are illustrated by graphs generated by measured information. A query field offers the user the possibility to ask data of a specific period in a certain interval or to export sensor data for further analysis in other software tools. Both systems supported this thermal performance analysis.

3.2.1 Weather Data

Weather conditions influence a building's thermal performance to a certain extend: heating demand raises with cold outside air temperatures, solar collectors work more efficiently with high solar radiation, for instance. In order to examine the influence of outdoor climatic conditions on the thermal performance, a weather station (Wireless Vantage Pro 2 Station, Davis 2012) has been installed on NAT's roof (Figure 24 and 25). It records data about outdoor air temperature, relative humidity, wind speed, wind direction, rain rate, and air pressure. These ongoing measurements started in February 2012.

Figure 24. Weather station Wireless Vantage Pro 2 Station.

Figure 25. Weather station installed on NAT'S roof.

Outdoor Air Temperature

The measuring period began in February 2012 and was considered until February 2013. Cold and warm periods in this specific year were illustrated in a plot of daily mean external air temperatures. In order to examine the influence of outdoor air temperature on the heating demand, these values were compared to aforementioned historical data analysis. In addition, the measurements of the outdoor air temperature were used to determine the heating days (Hd).

Heating Days (Hd) and Heating Degree Days (HDD)

Heating days (Hd) are defined as days, when the external temperature descended below the heating limit of 12 °C (ÖNORM B 8135 1983). Daily mean values are the basis for the calculation of Hd per year. The less Hd per year exist, the less thermal energy is required for heating.
Heating degree days (HDD) are a main influential factor on a building's heating demand. The more heating degree days, the more energy is required for heating. HDD are determined as the sum of temperature differences between a constant room temperature and the average outdoor temperature per day, if the outside air is equal or less than 12 °C (ÖNORM B 8135 1983). Related to OIB regulations (OIB Leitfaden 2 1999) and ongoing measurements at NAT, an indoor temperature of 20 °C was used for the computation. The result was compared to HDD guiding values from the area around NAT.
Heating degree days are required for thermal balance calculation of a building and consequently to state the heating demand.

Solar Radiation

The daily global radiation is denoted as the amount of energy irradiated by the sun while shining from dusk till dawn on a horizontal surface during one day (Wagner 2010). This heat affects the ground temperature, the warming up of the construction, and therefore the heating demand. Contiguous to this influence, the radiation is of main interest regarding the usage of the installations using solar energy. To calculate the solar gains of the mounted solar thermal system and photovoltaic panels at NAT, measurements of the global radiation at this specific location were analyzed. An overview of the daily global radiation metering has been depicted in a graph for the observation period February 2012 - February 2013.

3.2.2 Indoor Environment Conditions

Indoor thermal climate indicates parameters affecting the body-heat balance of a human being. As a general rule it is the aim to create an ambient atmosphere for the user with the room climate. (Fanger 1994)

Internal climatic conditions are influenced by various factors, e.g. ambient air temperature, relative humidity (ASHRAE 2004). These measurements were analyzed towards thermal comfort conditions.

During the further procedure, presence of people, CO_2 concentration, and infiltration were observed for a certain period in order to conclude with air quality conditions at NAT.

The measurements focalized on winter time in order to analyze the thermal performance and the heating demand. The focused period started with the 20th September 2012 and lasted until the 31st January 2013.

Occupancy

The presence of people in a room or zone affects the indoor climatic conditions intensively. One adult person has a metabolic rate of 0.8 met (1 met = 58 W per square meter body surface) in an inactive state. Each movement or activity raises his metabolism and consequently changes internal climatic conditions. (Fanger 1994)

In this work, the term *occupancy* describes whether a person visited a zone or not. Sensors recorded information about occurring movement and stored the event with a timestamp in the database. Data of hourly conditions were examined in order to meet realistic conditions. A Boolean reply informs whether occupancy was measured in this particular hour (1) or not (0). Based on this output, the occupancy frequency was reached with the sum of the received results. With this information, the date and quantity of occupancy was stated. In addition, the influence of occupancy on thermal comfort and heating behavior was studied.

Carbon Dioxide Concentration

The CO_2 concentration outdoors varies depending on the surrounding environment, but is measured with approximately 400 ppm (ÖNORM 13779 2005). Measurements inside a building might differ significantly depending on certain parameters: occupancy, room volume, user's activity, infiltration, ventilation, etc. (UBA 2008).
A comfortable room air quality is achieved with the so-called *Pettenkofer value*. According to Max von Pettenkofer (*1818 - †1901), the upper limit of carbon dioxide concentration in a room is denoted by 1000 ppm (UBA 2008). Low air quality is determined with more than 1400 ppm, whereas ventilation is required with more than 2000 ppm (UBA 2008).
NAT was equipped with sensors to measure carbon dioxide concentration in different zones of the building (Table 6). In order to analyze air quality conditions, the CO_2 concentration was examined in occupied hours. Based on monitored data, a graph was created to depict the measured maximum CO_2 concentration at NAT. Peak values occurred on days when occupancy was recorded, too. With this illustration, occupancy frequency and carbon dioxide concentration were put in relation.
In the further procedure, the focus was set on high frequented days with according high carbon dioxide concentration. With the help of the website tool (Schuß 2013), a specific day with occupancy and CO_2 concentration trends was analyzed.

Internal Temperature

The internal temperature is influenced mainly by presence of people and resulting heat emission (Lutz et al. 2002). Activity, clothing, and metabolism affect this procedure and cause increased internal temperatures (Lutz et al. 2002). Latent heat gains by equipment and lighting occur additionally. Thus, the internal temperature in buildings is determined according to its usage. Table 7 summarizes guiding values of inside temperatures proposed for different institutions according to Austrian standards.

Table 7. Required internal temperatures in different building types according to OIB (OIB Leitfaden 2 1999).

Building	θ_i
Residential buildings, Offices, Schools	20 °C
Hospitals, Nursing homes	22 °C
Industrial buildings	18 °C

Internal temperatures of each zone at NAT were recorded by the monitoring system. These measurements were plotted for the observation period in comparison to the outside air temperature. Monthly average values were listed per zone in addition to the external temperature. In order to analyze the heating behavior, the indoor air temperatures were considered during the winter period September 2012 to January 2013.

Thermal Comfort

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Inc. describes thermal comfort as that condition of mind that expresses satisfaction with the thermal environment (ASHRAE 2004). This state is influenced by environmental factors, e.g. temperature, humidity, radiation, and air movement (Szokolay 2004). Furthermore, people affect the indoor climate with activities, metabolism, or clothing. In this work, relative humidity, air temperature, and presence of people were considered for thermal comfort analysis. Therefore, occupied hours were established first.

Thermal comfort conditions are illustrated as psychrometric charts in this work for each zone and month for the period from 5th November 2012 to 31st January 2013, when occupancy was recorded.

Infiltration and Air Change Rate at NAT

Infiltration denotes the air volume flow, which occurs in a building through the envelope openings, e.g. walls, windows and doors that are closed (Panzhauser 2003). Due to cold outside air entering the heated interior room through any opening, the internal temperature might be affected in case of temperature differences. Thus, heating demand and energy use vary accordingly.

In opposite to ventilation, the infiltration transpires in an uncontrolled manner.

Infiltration leads to impacts on the air change rate of a building. The air change rate, commonly per one hour,

> *"is normally symbolized by ACH and is a measurement of how much fresh outdoor air replaces indoor air in a given time period"*
> (Bouhamra et al. 1998).

To get an impression about the tightness of NAT's envelope, the air change rate was computed based on the infiltration calculation. For this purpose, measured data of occupancy and CO_2 concentration was considered.
Information about infiltration concerning the building's envelope had to be gathered in periods with no occupancy. Otherwise, CO_2 generated by the occupants would have influenced the results. Consequently, a table listing occupancy counts and temporary related CO_2 concentration was created. For the further proceedings, it was necessary to detect periods when no occupancy occurred, the carbon dioxide concentration declined, but differed clearly from the outdoor CO_2 content of around 400 ppm.
First, the amount of passed time related to the adjacent hour of the first measurement had to be calculated for each considered value of the period. The result represented the percentage of the passed time to the start point. Lu et al. (2009) developed a formula to estimate space air change rate in case of no CO_2 generation (Equation 1). Based on the assumption that supply CO_2 concentration is stable (Lu et al. 2009) with a value of 400 ppm, the formula was changed to Equation 2 in order to obtain the air change rate at NAT.

$$C(t_1) = C_o + (C(t_0) - C_o)e^{-lt} \quad (1)$$

with parameters:

$C(t_0)$	= indoor CO2 - concentration at time t	[ppm]
C_o	= supply CO2 - concentration (outdoor)	[ppm]
$C(t_1)$	= indoor CO2 - concentration at time 0	[ppm]
l	= air change rate	[$1.h^{-1}$]
t	= time	[h]

$$l = (\mathrm{Ln}\ (C(t_0) - C_o) - \mathrm{Ln}\ (C(t_1) - C_o) / (t_1 - t_0) \quad (2)$$

with parameters:

t_1	= end time of regarded period	[h]
t_0	= start time of regarded period	[h]

Data recorded by the monitoring system is stored in an event based manner. Thus, different time intervals are stored that are not identical in time. So, all the timestamps were regenerated in units of hour starting from the first measurement.

With the aid of this transformed equation, the air change rate at NAT was calculated for each measured zone. These results informed about the tightness of the building's envelope and consequently indicated effects on the heating demand. In addition, the findings have been used to calibrate a simulation model of thermal performance with NAT's individual data.

3.2.3 Provision of Thermal Energy

Heating System

Thermal energy was measured in order to analyze the building's heating demand and energy use. Table 8 summarizes the therefore installed sensors. Figure 26 illustrates the heating system with measuring devices.

Table 8. Sensors in the heating system and measurement information.

Sensor	Measures energy provided by
Scylar-met 1	Solar collectors
Ray-met 1	Underfloor heating - first floor
Ray-met 3	Underfloor heating - ground floor
Ray-met 2	Pellets burner

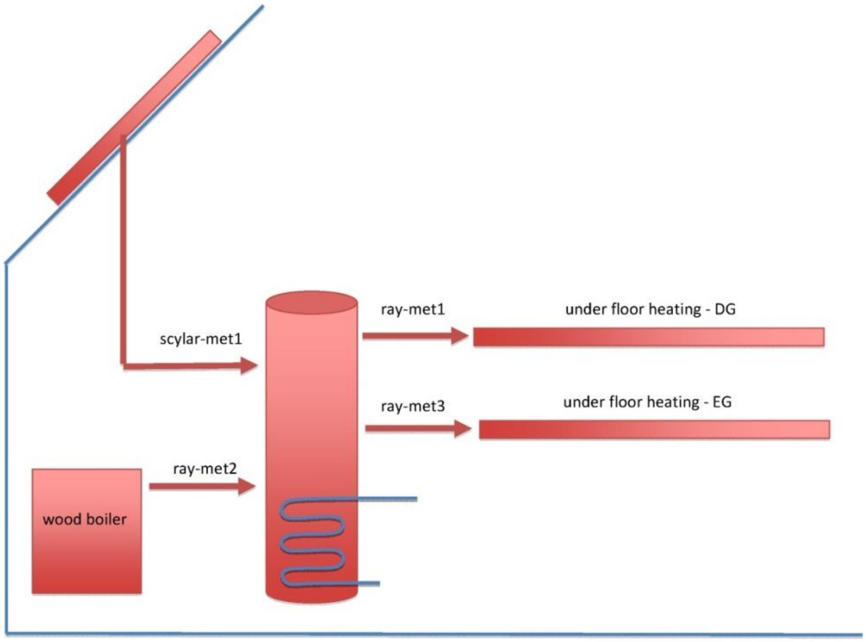

Figure 26. Schematic heating system with installed sensor types (Figure: M.Schuß).

The solar thermal collector system transports the collected energy from the roof to the storage tank. These solar gains are recorded by the sensor *Scylar-met1* (EWT Scylar Int 8: Diehl 2012). The thermal energy for both floor heating circles, in the first floor and the ground floor, is metered each by *ray-met1* and *ray-met3* (EWT Ray: Diehl 2012). The amount of heat required by the burning of pellets is measured with the meter *ray-met2* (EWT Ray: Diehl 2012).

Provision of Heat by Burning Pellets

To start with the analysis of the heating demand at NAT, the activity of the pellet furnace was considered. Temperature fluctuations of circulating water in the system and heat provision by burning pellets were examined with the aid of the monitored data. Thus, the date when the pellet furnace had to start firing and to support the heating system was stated. In the further procedure, the results were put in climatic context.

The energy conducted to the systems could be calculated based on information from the installed heat meters. The amount of heat required by each system was summed up to compare the results monthly. In respect to heating system analysis, the observation period was in winter from October 2012 to January

2013. Based on these results, the heating demand by burning pellets per square meter was stated for this period.

Provision of Thermal Energy by the Solar Collector System

In order to supply NAT on demand with heat and warm water sufficiently, the storage tank needs to keep a certain temperature. Both systems are in charge, the solar thermal system at first instance, and then the pellet furnace.
The solar collectors contain a liquid for heat transportation purposes. Its temperature rises according to the incoming solar radiation and external air temperature. The fluid leads the heat from the solar collectors to the reservoir but not before it exceeds the temperature of the storage tank. If the temperature of the water in the tank exceeds the circulating liquid’s temperature, the potential energy gain by the solar collectors won't occur. Consequently, the solar gains are not fed into the system, when the internal temperature is in excess. If the temperature in the tank is lower, the solar collector system provides energy to the heating system. Information about incoming solar energy was measured as far as the input and output temperatures of the liquid in the solar collector system.
Energy provision by solar radiation was compared to the heat transmitted by the solar collectors from 20th September 2012 to 20th January 2013. The aim was to show solar gain potential on specific days. Incoming solar radiation and energy generated by the thermal collectors were listed for each month of the aforementioned observation period. The results were put in relation to heat provision by burning pellets.

Efficiency of the Thermal Collector System

The monthly sum of the incoming solar radiation related to the heat produced by the solar thermal collectors at NAT informs about the system’s efficiency. Consequently, the efficiency of the system was calculated referred to the area of collectors installed on NAT's roof per month.

Warm Water Demand

ÖNORM B 8110-5:2010 states the warm water demand for a single family house about 35 $Wh.m^{-2}.d^{-1}$, for a multifamily house about 70 $Wh.m^{-2}.d^{-1}$. NAT was planned as an office building with combined residential facilities for groups. Thus, it was to assume that the warm water demand will differ from the standard guiding values.

The amount of water used at NAT was monitored. The heat required to warm up the demanded water is contained in the overall energy use. This energy is achieved with the Equation 3.

$$heat_{WW} = (raytin2 - Tem_{Water} - \Delta\, d\,) \cdot c_{\,w} \cdot waterflow1 \qquad (3)$$

with parameters:

$heat_{WW}$	= amount of heat to warm up required water	[Wh]
raytin2	= temperature of incoming water to the pellets furnace	[K]
Tem_{Water}	= temperature of incoming water to the system (from outside)	[K]
Δ d	= temperature difference of losses within the system	[K]
c_{w}	= specific heat capacity of water = 4.2 [$kJ.kg^{-1}.K^{-1}$] = 1.16	[$Wh.l^{-1}.K^{-1}$]
waterflow1	= water flow within the pipes	[$l.h^{-1}$]

In order to state the heating demand, the heat required to warm water had to be determined, too. The difference between the energy demand and the heat needed for domestic hot water yields the heating demand.

The amount of domestic water needed at NAT has been recorded by the installed monitoring system. In addition, the heat required to warm the water has been metered. These measurements have been compared to Austrian standard values per month.

Heating - Relation of Pellet Furnace and Solar Collector System

In order to yield an efficient energy use of a combined system, pellet furnace and solar thermal collectors have to be configured well. Reservoir capacities have to be sized according to the building's usage. Circulating liquids have to be calibrated to an adequate temperature in order to transport heat efficiently. These parameters were considered with the installed monitoring system.

In reference to the web tool (Schuß 2013), various abnormalities considering the heating system were observed and analyzed. Based on this analysis a more efficient use of the system was suggested.

3.2.4 Electricity

Electricity Use and Gains

In order to state an overview of electricity needs and the use of renewable energy sources in this context, appropriate sensors were included in the monitoring system.
NAT's photovoltaic facilities are serviced by the implementing company. They take care of the panel installation and store information about solar gains within the installation. Repeatedly in a year, a technician visits the building to collect the measured data from the photovoltaic system. The administration of NAT receives this information as csv - file with the specifications of energy [Ws], voltages [V], and amperage [A] of alternating and direct current recorded in five minutes intervals. With the following Equation 4, the electricity generation can be calculated for each current:

$$E_{el} = U \cdot A \cdot t / 1000 \tag{4}$$

With parameters

E_{el}	= Electric energy	[kWh]
U	= Voltage	[V]
A	= Amperage	[A]
t	= Time	[h]

Hourly values of alternating current were calculated in order to compare the energy gains transformed to the overall electricity use. The amount of electricity generated by the photovoltaic panels was compared to the electricity taken from local grid and fed-in to the grid for each month from October 2012 to January 2013.
The energy output of photovoltaic generators is proportional to radiation (Wagner 2010). Incoming global radiation and external temperature were considered based on the measurements of the weather station at NAT in order to

analyze the relation between solar radiation and energy generation. One exemplary day in summer 2012 was chosen as an example to illustrate the results.

System Efficiency

An economic use of a photovoltaic system requires panels mounted in south orientation, long sun shine duration, and avoided shading (Pistohl 2007a).
The energy output is described as the ratio of the energy generated by the system to the incoming solar radiation in relation to the area of the photovoltaic panels installed. The efficiency of a system describes to which extend the incoming solar power could be converted in electrical energy. (Konrad 2008)
A photovoltaic installation consists of several parameters. First, the incoming solar energy on the photovoltaic panels is converted into electrical energy (Pistohl 2007a). This has to pass several current activators and invertors (Figure 27), before it is either fed-in the grid or used by the building's occupants. Figure 27 shows important parts of the system at NAT schematically.

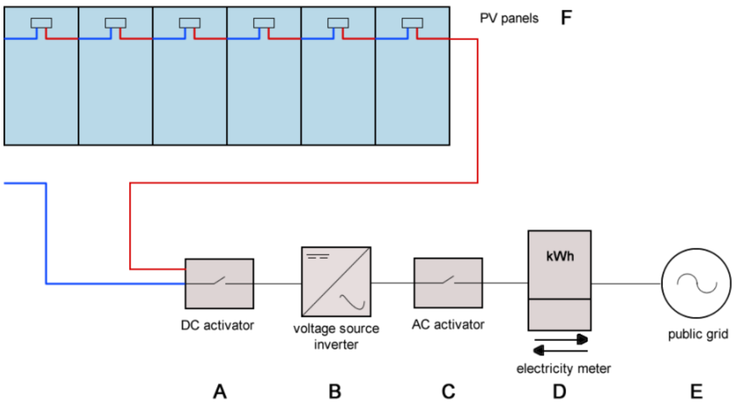

Figure 27. Schematic extract of photovoltaic installation at NAT. A: Direct current (DC) activator. B: Voltage source inverter (VSI). C: Alternating current (AC) activator. D: Electricity meter. E: Public grid. F: Photovoltaik panels. (Picture based on Raymann ® Kraft der Sonne)

Each device takes a bit of the energy produced by the solar cells and thus reduces the energy output of the system. The efficiency factor of an inverter for instance is announced with 90 – 97 % (Pistohl 2007a). Depending on the material characteristics used, the solar cells are measured with an efficiency of 10 – 18 %

(Pistohl 2007a). These measurements are based on experiments of optimal conditions: radiation of 1000 W.m^{-2} and ambient temperature of 25 °C (Pistohl 2007a). The amount of energy generated depends on the system itself. Blue Chip Energy announced a module efficiency of 14 % for the panels installed at NAT (BCE 2013). The inverter at NAT works with an efficiency of 97 % (Fronius 2013). Figure 28 shows the efficiency of the inverter plotted to the standardized output power. The productivity of the solar cells depends also on the module temperature (Pistohl 2007a). Figure 29 illustrates the relation between ambient temperature and output power under standardized conditions.

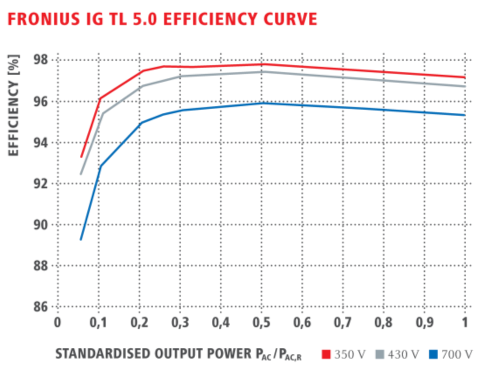

Figure 28. Efficiency and standardized output power of inverter installed at NAT (Picture: Fronius 2013).

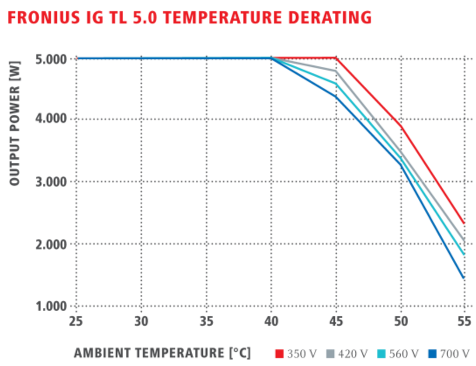

Figure 29. Ambient temperature and output power of the inverter installed at NAT (Picture: Fronius 2013).

In summer, the modules can reach a temperature of 30 – 60°C or even more (Pistohl 2007a). According to Figure 29, the output power decreases significantly with increased ambient temperature at NAT.

Based on the data gathered by the monitoring system and information provided by the installing company as mentioned before, the efficiency of the photovoltaic system at NAT was calculated. The measured energy output was related to the recorded global radiation and the area of the panels installed. The results had to be multiplied by the efficiency reduction factors of the system (0.14 x 0.97). Finally, the efficiency of the photovoltaic system was calculated for one specific month (October 2012). In addition, the overall efficiency was stated.

3.4 Building Performance Evaluation

3.4.1 Annual Balance to Determine NAT's Heating Demand

The heating demand of NAT has been determined by an annual balance according to EN 832 (OIB Leitfaden 2 1999). Heat losses through transmission and ventilation are factored in the energy balance as well as internal and solar gains. The dependence is described in Equation 5. Table 9 explains parameters used and factors required.

$$Q_h = (Q_T + Q_V) - \eta \cdot (Q_i + Q_s) \qquad (5)$$

Table 9. Parameters and factors used in the thermal heat balance (OIB Leitfaden 2 1999).

	Description	Formula	Unit
Q_T	Heat losses through transmission	$0.024 \cdot L_T \cdot HGT$	[kWh.a^{-1}]
L_T	Guiding value of the building's envelope		[W.K^{-1}]
HGT	Heating degree days		[Kd]
Q_V	Heat losses through ventilation	$0.024 \cdot L_V \cdot HGT$	[kWh.a^{-1}]
L_V	Guiding value for ventilation of the building's envelope		[W.K^{-1}]
Q_i	Internal gains	$0.024 \cdot q_i \cdot BGF_B \cdot HT$	[kWh.a^{-1}]
q_i	Heat flow		[W.m^{-2}]
BGF_B	Gross heated floor area		[m^2]
HT	Heating days		
Q_s	Solar gains	$\sum[I_j \cdot A_{gj} \cdot f_{sj} \cdot g_{wj}]$	[kWh.a^{-1}]
I_j	Sum of radiation with orientation		[kWh. m^{-2}.a^{-1}]
A_{gj}	Glazed area of each orientation		[m^2]
f_{sj}	Reduction factor for shading of each orientation		
g_{wj}	Effective overall energy transmittance		
η	utilization factor		

For the calculation of NAT's heating demand, all necessary parameters have been computed. U-values were calculated according to material characteristics information. Some of them differed from the announcements of the architect due to varying parameter settings.

The equation was also used for the static energy certificate generation. This annual balance considered the HDDs that were calculated based on monitored data of the weather station at NAT. Thus, the result is specific for the year 2012 and not influenced by average values as it is in the calculation software.

3.4.2 Energy Certificate

Buildings in Austria have to be classified according to their energy demand, as mentioned before. Therefore, the energy certificate for NAT was created. In order to get an overview about the position of NAT in the standard's heating demand range, the energy certificate was generated for different points in time according to changes in the regulations.

Therefore, the program ArchiPhysik version 10 (A-NULL 2012) was used. The calculation is based on parameters defined by the Austrian standards and guidelines listed in Table 10. ÖNORM B 8110-6 (2010) provides the main principles for heating demand calculation formulated for Austria.

Table 10. Austrian standards as basis for energy certificate calculation in Archiphysik.

Norm	Title
OIB Richtlinie 6:2011	Energieeinsparung und Wärmeschutz
ON B 8110:2010-5/-6	Klima, Nutzprofile / HWB und KB
ON H 5056:2011	Raumheizung und Warmwasser, Luftheizung für Nicht-Wohngebäude
ON H 5057:2011	Raumlufttechnik
ON H 5058:2011	Kühltechnik
ON H 5059:2010	Beleuchtung mit Benchmark-Werten

Archiphysik databases provide information about material characteristics, building elements, location, and climatic conditions to adjust the calculation of a specific building (Battisti 2012).

Output and Classification

The output of this calculation is an energy certificate that provides information about the energy use in the building. The building's specific heating demand related to a reference climate is classified and illustrated on a scale (Figure 30). Table 11 shows the heating demand classification defined by OIB RL6 (2011).

Table 11. Building classification according to heating demand (HD) [$kWh.m^{-2}.a^{-1}$].

Class	A++	A+	A	B	C	D	E	F	G
HD	≤ 10	≤ 15	≤ 25	≤ 50	≤ 100	≤ 150	≤ 200	≤ 250	> 250

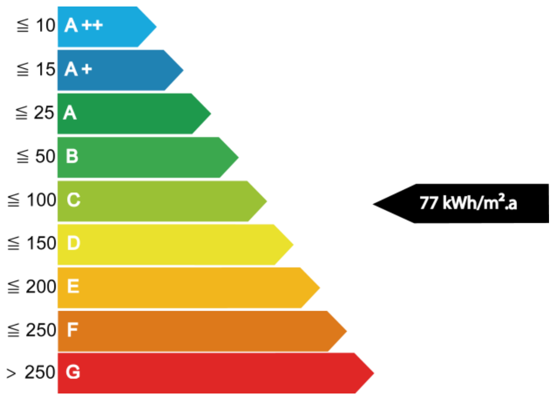

Figure 30. Building classification scale of Austrian energy certificate (based on A-NULL 2012).

Generation of Energy Certificates According to Changing Requirements in Guidelines

During the lifecycle of NAT, standards and guidelines changed. Different energy certificates were calculated according to each requirement modification. Hence, seven scenarios were elaborated. Characteristics of the building prior to the refurbishment were considered in the first scenario. Second, the heating demand was generated with input values of minimal requirements of 1988. Chronologically, the energy certificate of the refurbishment itself was generated next. Further energy certificates were calculated with minimal demands of the years 1996 and 2012. In order to compare NAT to today's passive house conditions and classify the results, these cases (with and without ventilation system) were also calculated. Thus, the heating demand results were put in relation and the building was classified according to requirements of the time of construction and today. These results showed tendencies in classification and displayed changes over the years.

In order to compare the building in different scenarios, a common basis had to be set. NAT has been defined as a hotel, as occupancy and temperature patterns seemed to meet the usage characteristics.

Influences of Different Parameter Settings on the Energy Certificate Results

The regulations allow different assumptions to generate an energy certificate. The initial case, the refurbishment (see above), is based on default assumptions of the regulation on occupancy and infiltration of a hotel. NAT is not defined clearly as its usage is combined both office and residential. However, different assumptions can be made regarding the occupancy and infiltration. On the other hand further investigations of the building operation provide more accurate information about the energy need. Consequently, different scenarios were created to analyze influences on the heating demand by variation of input parameters based on this initial case (NAT refurbished) discussed before. The aim was to detect the main parameter that causes the highest deviation.

The scenario of NAT refurbished was adjusted according to different usage and occupancy schedules, also in respect to its actual use. These scenarios were calculated twice: defined as residential building and without specification. Further changes were applied in daily occupancy, duration of usage, and air change rate. The internal temperature has been set to 20 °C in each case, according to the guidelines (OIB Leitfaden 2 1999). Table 12 depicts the number of occupied days of office and NAT schedule. The differences between the scenarios are described in Table 13.

Table 12. Schedule of occupied days per month for office case and NAT.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Schedule**
Days of use	23	20	23	22	23	22	23	23	22	23	22	23	Office (O)
	23	0	0	20	20	20	14	14	14	23	22	23	NAT (N)
	22	22	22	22	22	22	22	22	22	22	22	22	Week (W)

Table 13. Input parameters of modification for each scenario.

	Initial case	Modification								
	NAT refurbished	1	2a	2b	3a	3b	4a	4b	5a	5b
Residential building	No	Yes	Yes	No	Yes	No	Yes	No	Yes	No
Period	Year	Year	Oct-Jan	Oct-Jan	Year	Year	Year	Year	Year	Year
Schedule	D	D	D	D	W	W	O	O	N	N
ACH [h^{-1}]	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.7	0.4	0.4

3.4.3 Thermal Simulation

Today's performance characteristics are defined in standards and guidelines. Regulations and real measurements of a building may differ significantly due to individual use. Thus, NAT was analyzed towards both requirements. First calculations of the heating demand were generated based on standardized inputs. Measurements of the monitoring system were considered in the further procedure in order to meet the actual needs. Input parameters were not clear enough to categorize the building indeed.

With a dynamic thermal simulation, the adjustments can be set more precise than in a static calculation program. Specific periods of individual interest can be analyzed and changes of input parameters show differences in energy use directly. Thermal simulation software is a powerful tool in order to analyze a building with regard to multilayer performance characteristics. The goal is

> *"[…] to improve design, construction, operation, and maintenance of new and existing buildings […]"* (IBPSA 2013).

The aim in this case study was to state influencing factors on NAT's energy demand. Based on the output, energy saving potentials could be detected. Therefore, a sensitivity analysis was conducted first. Case studies were developed subsequently in order to examine the building's energy use. The software EDSL TAS (EDSL 2012) was used to simulate the building's thermal performance.

Sensitivity Analysis

The sensitivity analysis aimed to examine factors of major influence on the thermal performance of NAT. Therefore, different scenarios were elaborated and simulated. These scenarios vary in occupancy hours, internal temperature, and infiltration rate. According to the changes in the simulation input, heat gains and losses were compared in order to state the influence of different parameters on the heat flow in the building. Different scenarios were created based on the measured data. The results were opposed to scenarios adjusted with standard requirements of office and residential buildings.

Evaluation of Energy Saving Potential by Thermal Simulation

To state energy saving potential at NAT, the simulation model has to match the real situation as close as possible. Hence, the simulation model calibrated with measured information (M#) was analyzed for the aforementioned monitoring process observation period (October 2012 – January 2013). Results for the entire year were developed by the simulation tool.

The infiltration was the most uncertain parameter in this simulation due to calculation based on short term measurement values of carbon dioxide concentration. Hence, this value was adjusted to finally reach the realistic heating demand for this period according to prior data analysis. This resulted in different scenarios in order to detect energy saving potentials. Therefore, inputs of occupancy, internal temperature, and construction material characteristics were changed.

3D Model and Zoning

Before the simulation, the building had to be drawn with the software tool TAS 3D Modeller (EDSL 2012). Based on these plans, a 3D model of each floor was generated. Figure 31 shows the model of NAT in TAS schematically.

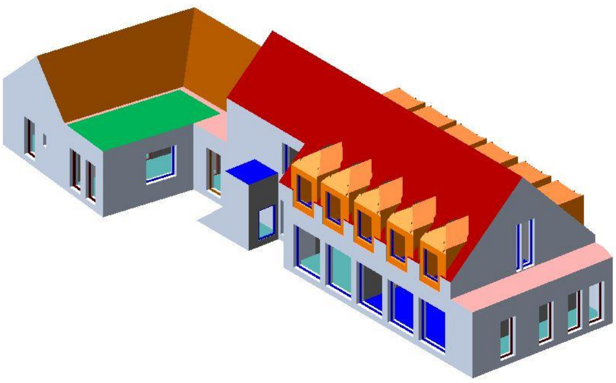

Figure 31. 3D model of NAT by TAS 3D MODELLER (EDSL 2012).

In order to apply varying input parameters of different use cases to the building, the model was divided in different zones according to usage characteristics of

NAT. Figures 32 and 33 illustrate the zoning in TAS, Figure 34 informs about the applied zones in the model.

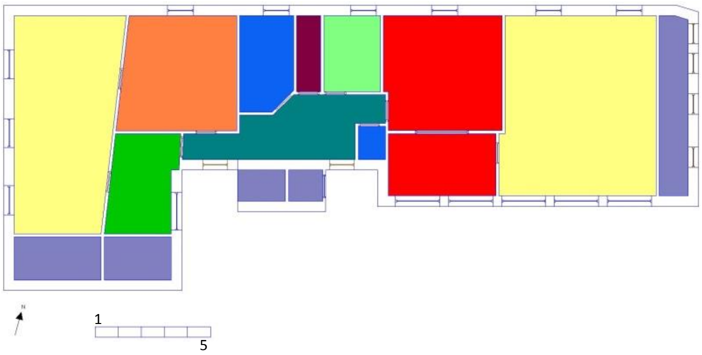

Figure 32. Zoning in TAS (EDSL 2012): Ground floor of NAT.

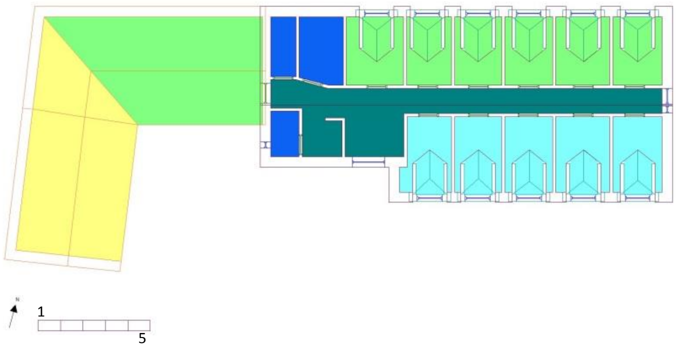

Figure 33. Zoning in TAS (EDSL 2012): First floor of NAT.

Figure 34. Applied zones at NAT in TAS 3D MODELLER (EDSL 2012).

After the model had been determined, building elements and characteristics were defined in TAS Building Simulator (EDSL 2012). All the elements that were used (walls, roofs, windows, ceilings, doors, etc.) were specified in the construction database.

External Conditions

In order to put the simulation model in realistic context, external conditions were defined. These are weather influences, surrounding buildings, and shading devices.

Based on recorded data from the installed weather station at NAT, a weather file was created for the simulation. It contains information of one year from February 2012 to February 2013. This file was used for all simulations done in this analysis process. It provides information about outdoor temperature, relative humidity, solar radiation, wind speed, and wind direction.

The surrounding environment was designed with the 3D Modeller (EDSL 2012). The terrain type was set to rural in the Building Simulator (EDSL 2012). However, the simulations did not show any influences on the results. The distance and height of these constructions have no impacts on NAT's performance. Shading elements don't exist at NAT and were consequently not applied in the model.

Model Calibration

The model was calibrated in order to match closely with the measured performance values of the building monitoring (Claridge 2011). A common basis was set with a weather file. In addition, the internal conditions were applied. Information about temperature and occupancy received from recorded data was set in the simulation program. Infiltration values were calculated per zone based on measured data of occupancy and carbon dioxide concentration.

The resulting heating demand of the simulation was compared to the former investigated value. After adjusting the model, it was calibrated closely to the real performance recorded.

In order to compare simulation results to standard requirements, the model had to be adjusted according to related guiding values in a second case. Therefore, the standards ÖNORM EN ISO 13790 (2008) for the calculation of the heating demand and ÖNORM B 8110-5 (2010) for thermal protection of buildings were considered in order to set internal conditions. Temperature, infiltration, and occupancy schedules were addressed.
Occupancy and usage scenario were distinguished in office buildings and family houses in order to approach the utilization of NAT. Finally, different basic simulation cases were created: standard office (SO), standard one family house (SF), and measured NAT (M#).

Internal Conditions

Parameters that influence internal conditions were set in the TAS Building Simulator (EDSL 2012). Occupancy schedule, calendar, temperature, infiltration, and heat gains have been considered.
The internal heat gains in office and residential buildings were set at a value of 3.75 $W.m^{-2}$ according to ÖNORM B 8110-5 (2010). This guiding value has been reached by summing up the heat gained by lighting, occupancy, and equipment in the simulation. Other input parameters were set differently in each scenario.

Occupancy

The occupancy in a building can be set in the simulation program via schedules. Figure 35 shows a matrix of occupied hours per zone for one representative day. 1 stands for people present in a particular hour, while 0 stands for no occupancy. This schedule was changed according to office hours from 8 a.m. to 5 p.m. in case of SO. Presence of people in the one family house (SF) was assumed to take place 24 hours per day.

Schedules

Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Ancillary	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Bath	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0	1	1	1	0	0	0	0
Bedroom	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
cellar	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
corridor	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0
Kitchen	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0
Office	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Groups_seminar room	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
staircase	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0
storage room	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Whole day	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 35. Occupied hours per zone at NAT for one day (EDSL TAS 2012).

Calendar

The calendar for the entire simulated year had to be adjusted in all cases according to occupancy and usage of the building. A representative illustration is to be found in the appendix. The calendar of the one family house (SF) kept the same usage on every day. Days in office case (SO) varied with working days, bank holidays, and weekends.

Temperature

The internal temperature for the simulation input was based on values recorded by the monitoring process. Zones without any measuring device were adjusted with values according to standard ÖNORM B 8110-5 (2010). Table 14 summarizes the internal temperature input of each zone in the simulation model. Only one zone was necessary for the cases of one family house (SF) and office (SO) related to standard conditions.

Table 14. Input values of internal temperature [°C] and infiltration [h^{-1}] for the simulation model of NAT for the different base cases.

Case	Zone	Temperature	Infiltration
M#	Ancillary	14	0.36
	Bathroom First Floor	22	0.36
	Bathroom Ground Floor	20	0.41
	Bedroom North	20	0.42
	Bedroom South	20	0.41
	Cellar	20	0.36
	Corridor	21	0.36
	Corridor First Floor	21	0.36
	Group Bedroom	15	0.33
	Kitchen	20	0.49
	Office North	20	0.28
	Office South	20	0.41
	Seminar Room East	20	0.47
	Seminar Room West	17	0.49
	Staircase	14	0.36
	Storage Room	14	0.36
SO		20	0.40
SF		20	1.20

Infiltration

The infiltration was calculated for each zone monitored at NAT. The results were applied to the simulation model (Table 14). Standard cases (SF) and (SO) were adjusted according to guiding values given in ÖNORM B 8110-5 (2010).

4. RESULTS AND DISCUSSION

4.1 Historic Data Analysis

4.1.1 Energy Provided by Burning Pellets

NAT's administration provided information about yearly pellets purchase. Table 15 lists the amount of pellets ordered per year.

Table 15. Order of pellets [kg] per year.

Year	2006	2007	2010	2011	2012
Pellets	5250	5000	6000	6100	6500

As Table 15 shows, the quantity of pellets required increased since 2006. In 2012, NAT used 19 % more pellets than 6 years before. The administration of NAT announced a rise of visitors especially for the winter months due to advertising efforts. As a consequence, this led to an increased heating demand.
Table 16 provides an overview of energy required by burning pellets per month and year in kilowatt hours. The heat provided was related to area and year and listed below. Monthly mean values of energy use are listed additionally.

Table 16. NAT's energy demand [kWh] per month and year (a); per square meter and year [$kWh.m^{-2}.a^{-1}$] (en).

	2007	**2008**	**2009**	**2010**	**2011**	**mean**
Jan	3766	4344	4374	4429	3246	4344
Feb	3288	2969	3228	4415	4661	3288
Mar	1501	2025	2715	2728	2629	2629
Apr	n.a.	896	136	405	913	650
May	n.a.	358	n.a.	1474	n.a.	916
Jun	n.a.	n.a.	n.a.	576	n.a.	576
Jul	n.a.	n.a.	n.a.	177	461	319
Aug	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sep	n.a.	358	n.a.	271	466	358
Oct	n.a.	464	942.8	1700	1848	1321
Nov	5827	1361	2749.6	3084	3376	3084
Dez	3110	2450	3200.6	4169	3405	3201
a	17491	15225	17346	23428	21004	20685
en	**52**	**45**	**52**	**70**	**63**	**62**

Regarding the recorded data of the years 2007 to 2011, an average energy need of 62 $kWh.m^{-2}.a^{-1}$ was stated. The annual energy use was consistent with class C of energy certificate classification (OIB RL 6 2011). In 2008, the heating demand differed about 26 % from the average. In contrast, the energy demand increased by 13 % in 2010. These results had been supposedly influenced by weather conditions and occupancy. Figure 36 illustrates the mean monthly energy need at NAT for the years 2007 to 2011.

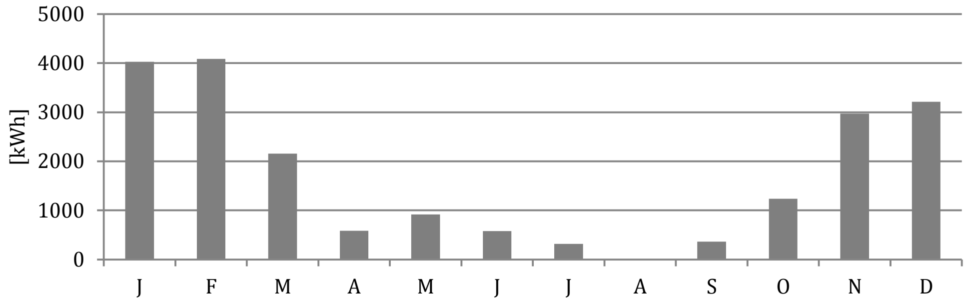

Figure 36. Mean monthly heating demand [kWh] at NAT of the years 2007 to 2011.

Considering mean values, February required the maximum amount of energy for heating in this particular observation period, followed by January, December, November, March, and October. August was the only month with no heating.

4.1.2 Energy Supply by Solar Thermal System

Information about energy gains from the thermal collector system was available for one entire year (2011) and several months of different years (2006, 2007, 2012). Monthly energy generation is listed in Table 17.

Table 17. Sum of solar thermal gains [kWh] at NAT per month for the years 2006, 2007, 2011, 2012.

	2006	2007	2011	2012	mean
Jan	n.a.	78	32	39	50
Feb	n.a.	312	392	219	307
Mar	n.a.	835	816	1193	948
Apr	n.a.	1509	1757	n.a.	1633
May	n.a.	1150	1610	n.a.	1380
Jun	n.a.	1054	1531	n.a.	1292
Jul	n.a.	1372	1027	n.a.	1200
Aug	n.a.	n.a.	1359	n.a.	1359
Sep	n.a.	n.a.	1655	n.a.	1655
Oct	494	n.a.	1070	n.a.	782
Nov	492	n.a.	57	n.a.	274
Dec	79	n.a.	17	n.a.	48

In 2011, an energy amount of 11323 kWh was generated with the solar collectors. The relation between global radiation and solar thermal gains for the year 2011 is illustrated in Figure 37.

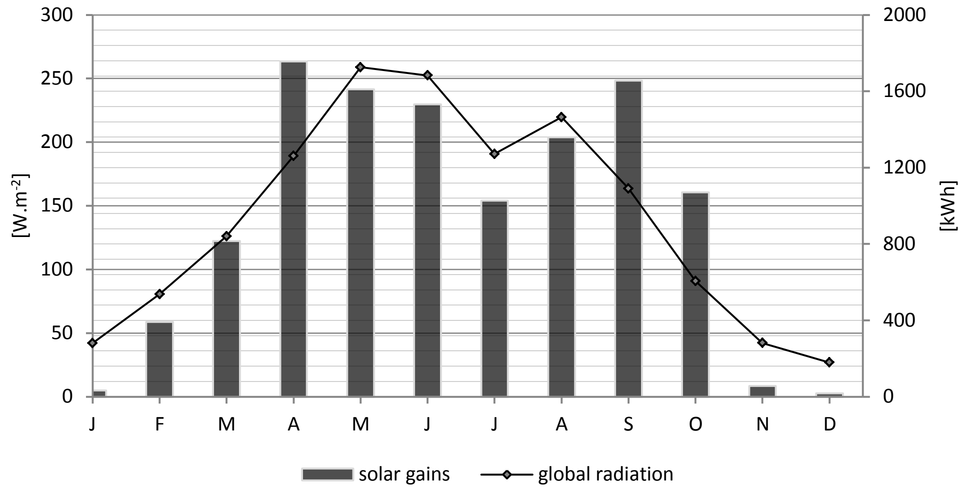

Figure 37. Monthly solar thermal gains [kWh] at NAT and mean monthly global irradiance [W.m-2] at ZAMG weather station Seibersdorf of the year 2011.

The values representing global radiation measurements (graph) ascended from January to May, whereas the solar thermal gains (bars) reached a first peak in April. Minimum values of global radiation and solar thermal gains have been measured in December. As shown in Figure 37, there was low radiation in July and therefore decreased solar thermal gains. In addition, it explained the relation of high solar gains and global radiation during the summer months compared to winter.

Total Energy Provided

The sum of heat provided by burning pellets and solar thermal collectors informed about the entire energy demand at NAT. Figure 38 illustrates mean solar thermal gains and pellet use per month for the years 2006, 2007, 2010, and 2011. Figure 39 shows monthly mean values of heat provision by solar thermal system and pellet furnace for the year 2011.

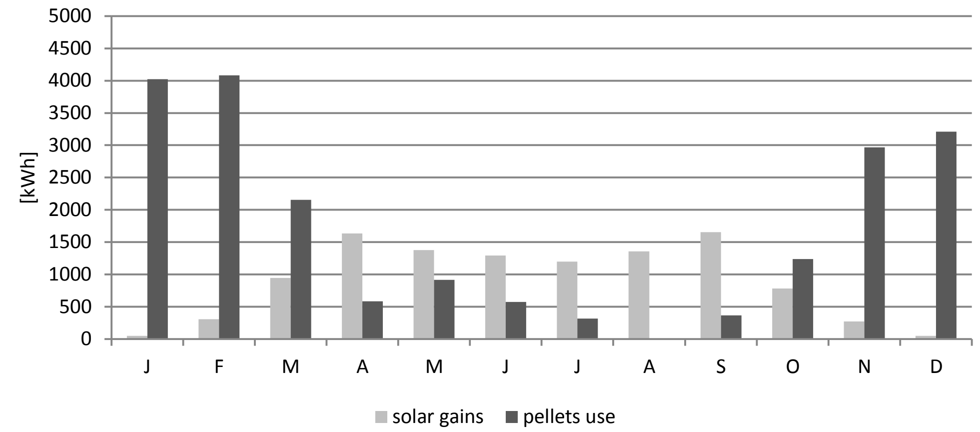

Figure 38. Mean values of heat provided by solar thermal gains and burning pellets [kWh] at NAT per month of the years 2006, 2007, 2010, 2011.

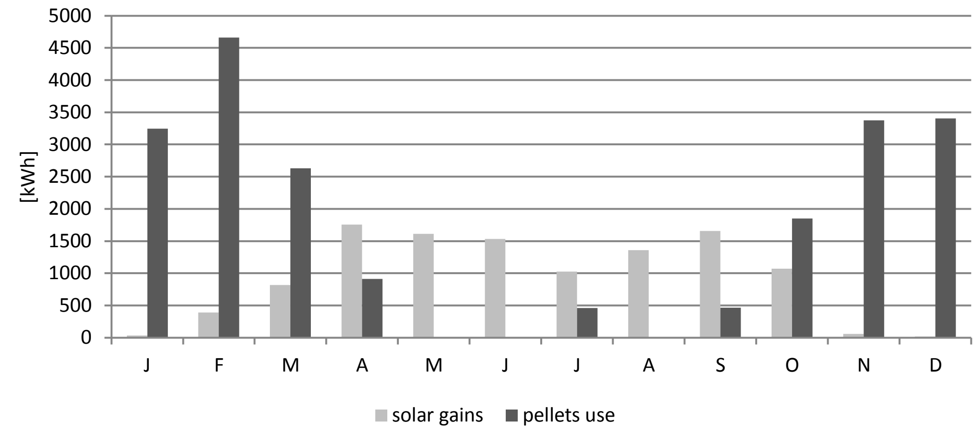

Figure 39. Monthly mean values of heat provided by solar thermal gains and burning pellets [kWh] at NAT in 2011.

The heat provision by the pellet furnace increased in the winter months (October to March) in order to cover the energy demand. Table 18 summarizes the amount of energy provided by the pellet furnace and the solar collector system and states the total energy demand in 2011 per month.

Table 18. Pellets use (P), solar thermal gains (S), and total energy demand (∑) [kWh] at NAT per month in 2011.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	∑
P	3246	4661	2629	913	-	-	461	-	466	1848	3376	3405	21004
S	32	392	816	1757	1610	1531	1027	1359	1655	1070	57	17	11323
∑	3278	5053	3445	2670	1610	1531	1488	1359	2121	2918	3433	3422	32326

According to these results, the amount of energy provided by burning pellets was of 63 $kWh.m^{-2}.a^{-1}$ for the year 2011. For the total energy need, the heat generated by the solar thermal system was added and increased this value to 96 $kWh.m^{-2}.a^{-1}$. Note that energy required for domestic hot water and heat losses by the system were included.

Energy Demand Covered by the Solar Thermal System

The ratio of solar gains to the entire thermal energy demand describes the percentage, to which extend the solar collector system covered NAT's energy need. Table 19 summarizes the percentages that were covered by the solar collector system.

Table 19. Thermal energy covered by solar thermal collectors at NAT per month of 2011 [%].

	J	F	M	A	M	J	J	A	S	O	N	D	∑
%	1%	8%	24%	66%	-	-	69%	-	78%	37%	2%	0%	35%

In comparison, NAT's specifications announced a potential coverage of 52 % (Deubner 1996). In 2011, the system generated energy to cover 67 % of the announced value.

4.1.3 Weather Data

Outdoor Temperature

Table 20 depicts mean values of outdoor air temperatures at ZAMG weather station Seibersdorf per month and year.

Table 20. Mean outdoor temperature [°C] at ZAMG weather station Seibersdorf for the years 2006, 2007, 2010, 2011.

	2006	2007	2010	2011	mean
Jan	- 4	5	- 2	0	0
Feb	- 1	5	1	0	1
Mar	4	8	6	6	6
Apr	11	13	10	13	12
May	15	18	14	16	16
Jun	19	21	19	20	19
Jul	24	22	22	20	22
Aug	18	20	19	21	20
Sep	18	14	14	18	16
Oct	14	9	8	10	10
Nov	7	4	7	3	5
Dec	3	0	- 3	3	1
mean	11	12	10	11	

According to the temperature measurements and the calculated mean values, the warmest year was 2007, the coldest one was 2010. Low external temperatures imply an increased heating demand related to warmer years. Compared to Table 16, this statement could be confirmed: The maximum energy demand was measured in 2010.

Solar Radiation

Increased solar gains were recorded in warm periods of the year. Figure 40 illustrates the total global radiation and the mean daily temperature at Seibersdorf for specific years based on the sum of mean hourly values. The highest solar gains were recorded in the period April to September in all considered years. Table 21 lists the mean monthly global radiation at Seibersdorf for the years 2006, 2007, 2010, 2011 explicitly.

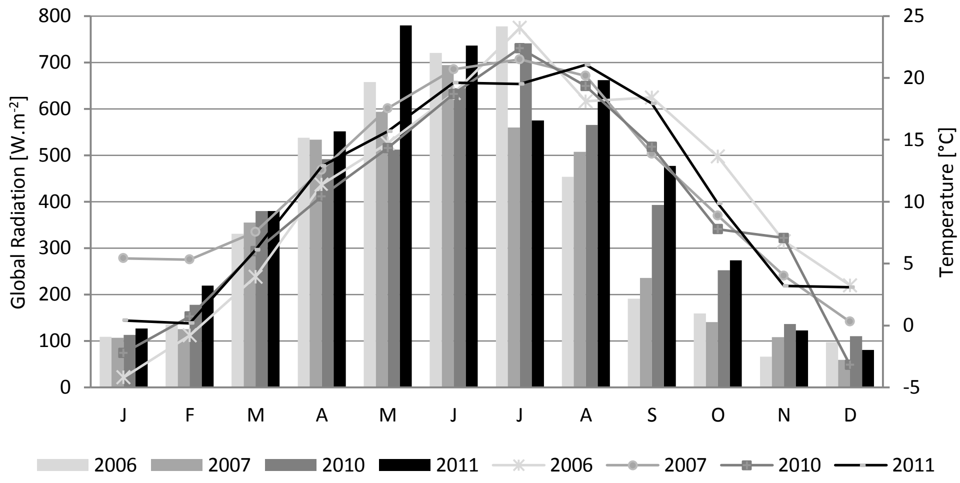

Figure 40. Mean temperature [°C] (graphs) and global radiation [W.m^{-2}] (bars) at ZAMG weather station Seibersdorf per month for the years 2006, 2007, 2010, 2011.

Table 21. Mean global radiation [W.m^{-2}] at ZAMG weather station Seibersdorf per month and year (2006, 2007, 2010, and 2011).

	2006	2007	2010	2011	Mean
Jan	109	107	113	127	114
Feb	135	125	178	219	164
Mar	331	355	380	380	361
Apr	538	534	491	552	529
May	657	594	512	780	636
Jun	720	695	645	736	699
Jul	777	560	741	575	663
Aug	453	507	566	662	547
Sep	191	236	393	477	324
Oct	159	140	252	274	206
Nov	66	108	137	123	109
Dec	97	59	110	81	87

4.2 Monitoring Process

4.2.1 Weather Data

Outdoor Air Temperature

The outdoor air temperature has been monitored since February 2012. Figure 41 shows the daily mean outdoor temperature trend from 2nd Feb. 2012 to 2nd Feb. 2013. During March, a malfunction of the measuring device occurred. Thus, a few days were not recorded. However, this circumstance had no impacts on the calculation of the heating days. According to other sources, the outdoor air temperature was higher than 12 °C.

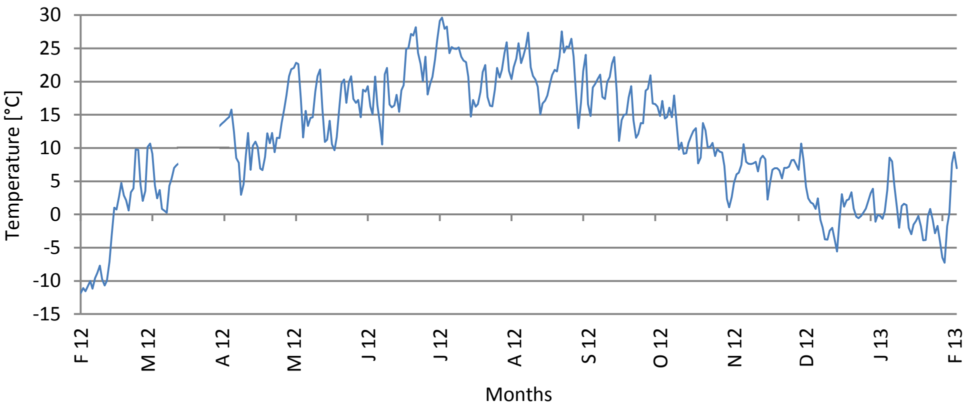

Figure 41. Daily average outdoor temperatures [°C] at NAT from 2nd Feb. 2012 to 2nd Feb. 2013.

February 2012 was the coldest month with a measured temperature less than -10 °C. A maximum value was recorded on the 3rd July 2012. The average temperature in this year was of 11.1 °C. In comparison to the historical weather data, this year was the warmest after 2007. High yearly average temperatures imply a lower heating demand in contrast to colder years. The heating period used to start in October. Due to warm outside air temperatures, the heating period is supposed to start later this year.

Heating Days (Hd) and Heating Degree Days (HDD)

Based on the temperature measurements at NAT, days with a temperature less than 12 °C were counted as heating days for the year February 2012 to February 2013. Table 22 depicts monthly mean outdoor temperatures and heating days per month for this period.

Table 22. Mean external temperature[°C] (T) and heating days (Hd) at NAT per month (M) and year (a) (February 2012 to January 2013).

M	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	Per a
T	-2.9	8.2	11.6	16.7	20.2	22.0	21.7	17.3	10.8	7.2	0.3	-0.2	11.1
Hd	28	26	16	6	1	0	0	2	19	30	31	31	190

According to this data, heating degree days (HDD) were calculated. As a result, $HDD_{20/12}$ at NAT counted 3094 Kd. In comparison to guiding values determined for contiguous locations of NAT, this result seems very low. A climate table from Graz University of Technology lists HDDs in Klosterneuburg, lower Austria (near Vienna), of 3245 Kd (Krischan 2013). Archiphysik (A-NULL 2012) database uses for energy certificate calculation of NAT in Petronell an average value of 3345 Kd. Less HDDs indicate a lower heating demand of a building. Consequently, the measured year is assumed to have lower energy needs in comparison to prior analyzed years.

Solar Radiation

Figure 42 shows the solar radiation measurements at NAT from February 2012 to January 2013. Due to high solar radiation recorded during the summer months April to September, this period is assumed to be most lucrative for energy generation by solar thermal systems and photovoltaic panels.

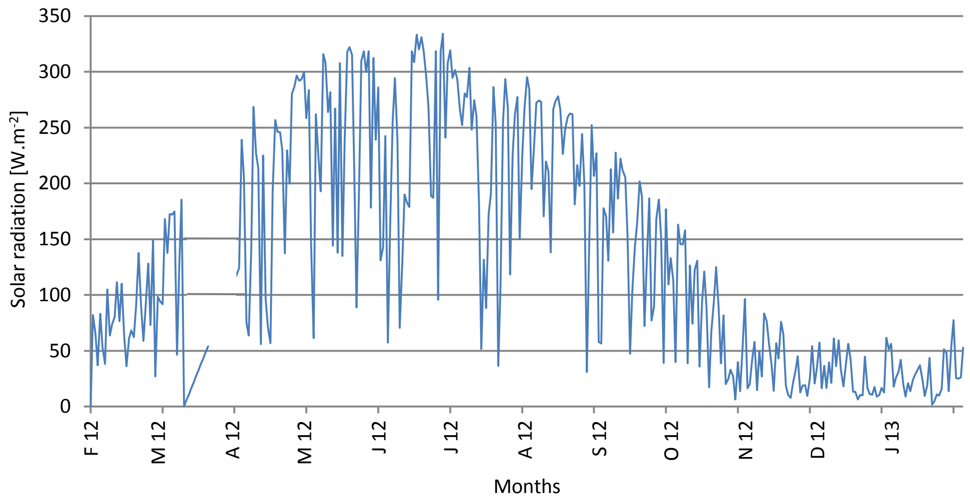

Figure 42. Daily average irradiance [W.m^{-2}] at NAT from 2nd Feb. 2012 to 2nd Feb.2013.

4.2.2 Indoor Environment Conditions

The analysis of indoor climatic conditions considered the period from 20th September 2012 to 31st January 2013.

Occupancy

According to event-based occupancy metering, the frequency of people present in a zone was stated. Therefore, the amount of occupied hours per zone was summed up. It represents the presence frequency at NAT. Table 23 shows the occupancy frequency of each zone per month for the observation period.

Table 23. Occupancy frequency at NAT from October 2012 to January 2013.

Zone	**1**		**2**		**4**	**5**	**6**		**7**	
Sensor	occ26	occ27	occ22	occ24	occ25	occ30	occ28	occ29	occ23	
O 12	45	63	110	120	53	99	53	66	3	**612**
N 12	82	105	177	181	214	216	157	155	61	**1348**
D 12	33	45	96	99	34	88	32	38	7	**472**
J 13	81	92	141	143	27	156	89	103	10	**842**
	241	**305**	**524**	**543**	**328**	**559**	**331**	**362**	**81**	∑

High occupancy implies an increased energy demand for heating, warm water, and electricity. According to the results in Table 23, the highest occupancy frequency was recorded in the kitchen (zone 5), followed by the office (zone 2).

Regarding monthly sums, the western seminar room (zone 6) was visited more often than the eastern lecture room (zone 1). Although zone 1 is adjacent to the daily used office, zone 6 at the other side of the building was occupied more often. This is probably due to groups visiting that area in comparison to the two person office. The bedroom for groups in the first floor was rarely frequented compared to other zones. In November solely, the number increased compared to other months, thus recording the highest occupancy. Hence, a major group was visiting NAT at that time. December was the month with the lowest occupancy in all zones. However, the energy required from November 2012 to January 2013 is assumed to increase compared to October. Therefore, the temperature decrease in this period based on measurements has been considered and compared to the energy use.

Carbon Dioxide Concentration

To state representative carbon dioxide concentration at NAT, hours with presence of people recorded were considered. Figure 43 shows the cumulative distribution of CO_2 concentration during the measuring period October 2012 to January 2013 of all zones.

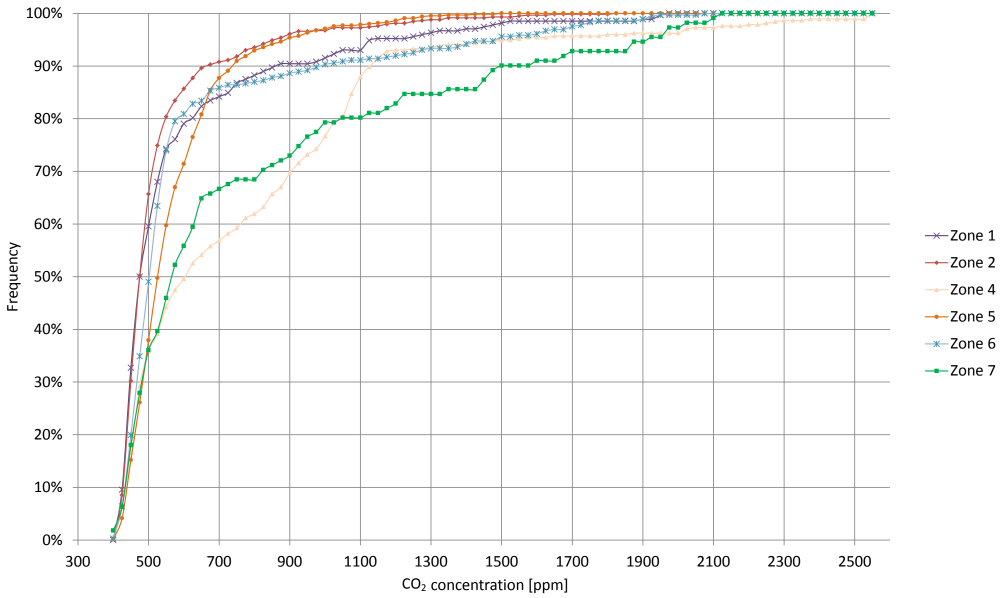

Figure 43. Cumulative distribution of CO_2 concentration [ppm] in all zones from October 2012 to January 2013.

According to Figure 43, the CO_2 concentration stayed in a comfortable range compared to the Pettenkofer value (UBA 2008). The measurements were mainly below 1000 ppm. In the bedroom ground floor (zone 4) the CO_2 concentration increased while occupied hours at night (Schuß 2013). This implies low ventilation in that area during occupancy. The other zones have been ventilated well either manually or due to air leakages in the building envelope.

In order to find high frequented days and the according maximum CO_2 concentration, a chart has been developed (Figure 62, Appendix). This illustration shows a density of occupied hours in mid-November. Accordingly, the carbon dioxide concentration increased significantly compared to other days. The 18th November 2012 was recorded with the highest CO_2 concentration. Figure 44 illustrates measured carbon dioxide concentration values for each zone at NAT on that day.

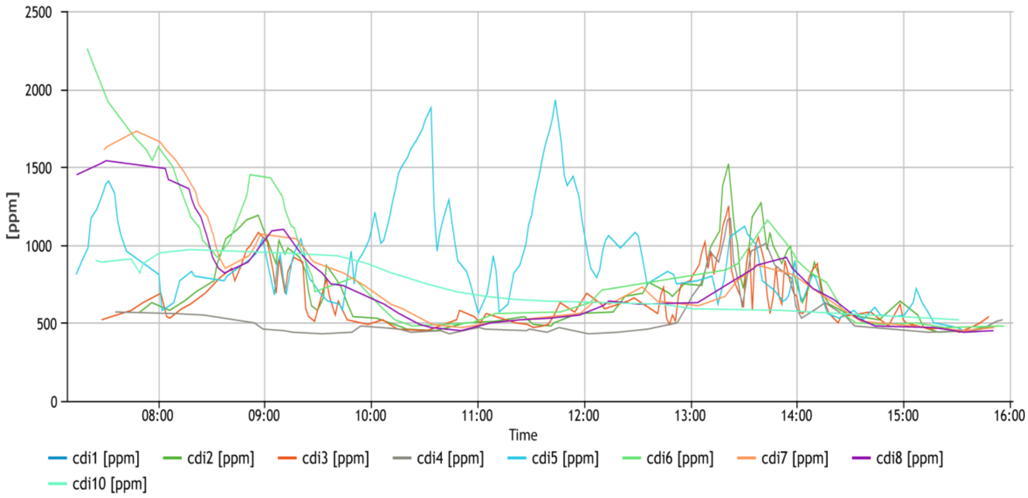

Figure 44. CO_2 concentration [ppm] at NAT (all zones) on 18th November 2012 [h] (UTC).

Zone 2 (cdi2) recorded maximum CO_2 concentration at night. Between 10 a.m. and noon, the kitchen (cdi5) measured peak values, presumably due to cooking. A decline at 11 a.m. implies either occupancy decrease or window opening. The next peak was measured in the office (cdi2) 1.5 hours later due to occupancy increase.

Internal Temperature

The internal temperature is one of the indicators for thermal comfort in a building. Additionally, it affects the heating demand significantly. Based on data of internal temperature recorded, trends of each zone have been compared to the outdoor air temperature, displayed in Figure 45 for the observation period September 2012 to January 2013.

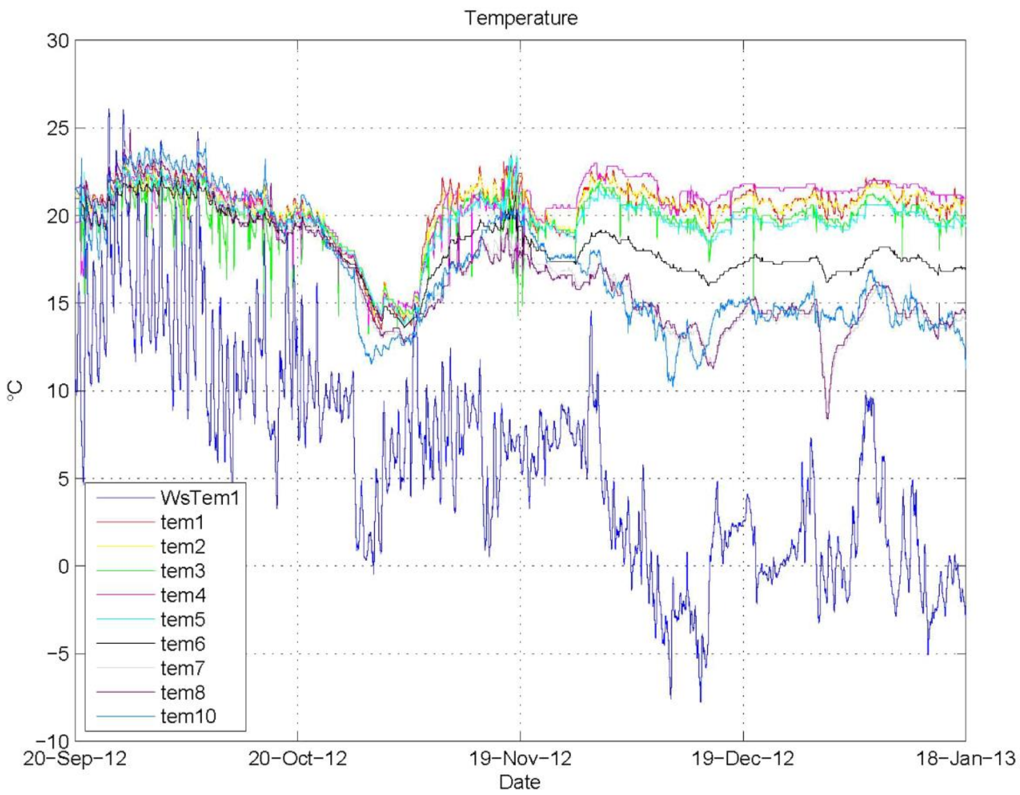

Figure 45. Internal and outdoor temperatures [°C] at NAT from 20th September 2012 to 18th January 2013.

At the end of October, both outside air and indoor temperatures decreased rapidly. With the beginning of November, internal temperatures increased again from around 15°C to more than 20°C, implying an increase of occupancy and heating. During the winter period, November to January, clearly differing temperature zones indoors had to be distinguished. Certain areas in the building kept a temperature around 20 °C, while other zones stayed around 15 °C. Monthly mean values of each zone were put in contrast to the according average outdoor temperature in Table 24.

Table 24. Mean monthly indoor temperature [°C] per zone and outdoor temperature [°C] at NAT, from October 2012 to January 2013.

Zone	1	2	3	4	5	6	7	8	9	Outdoor
Oct 12	20.0	20.0	19.5	20.0	19.9	19.5	19.9	19.6	20.0	10.8
Nov 12	19.6	19.6	19.6	19.6	18.9	17.5	16.4	16.2	17.0	7.2
Dec 12	20.9	20.8	20.0	21.6	19.8	17.4	14.0	14.1	14.2	0.3
Jan 13	20.4	20.4	19.5	20.8	19.4	17.2	14.1	14.5	13.6	-0.2

Seminar room west, office, corridor, bedroom and kitchen (zones 1-5) were heated to an average internal temperature of 20 °C during the observation period. The temperatures in seminar room east and bedrooms in the first floor (zones 6-9) decreased to a minimum of 14°C (December). Hence, these areas were heated less.

The temperature in the ground floor bedroom (zone 4) was measured with highest values (mean 21°C), whereas the kitchen (zone 5) showed a mean temperature of 19°C. Compared to the Austrian standard ÖNORM B 8110-5 (2010), the internal temperature was higher and lower in some areas as proposed by the regulation (20 °C).

The outdoor temperature was measured with a total decline of 11 K during the observation period. Accordingly, the indoor temperatures increased significantly. Thus, the heating demand was assumed to increase during this time.

Thermal Comfort

In order to state thermal comfort conditions at NAT, occupied hours were considered in this analysis. The comfort zone was defined according to ASHRAE standards for winter time: internal temperature between 20.0 and 23.5 °C, relative humidity in a range of 30 – 60 % (ASHRAE 2004).

Figure 46 shows a psychrometric chart of measured values in the office (zone 2) for the period November 2012 to January 2013.

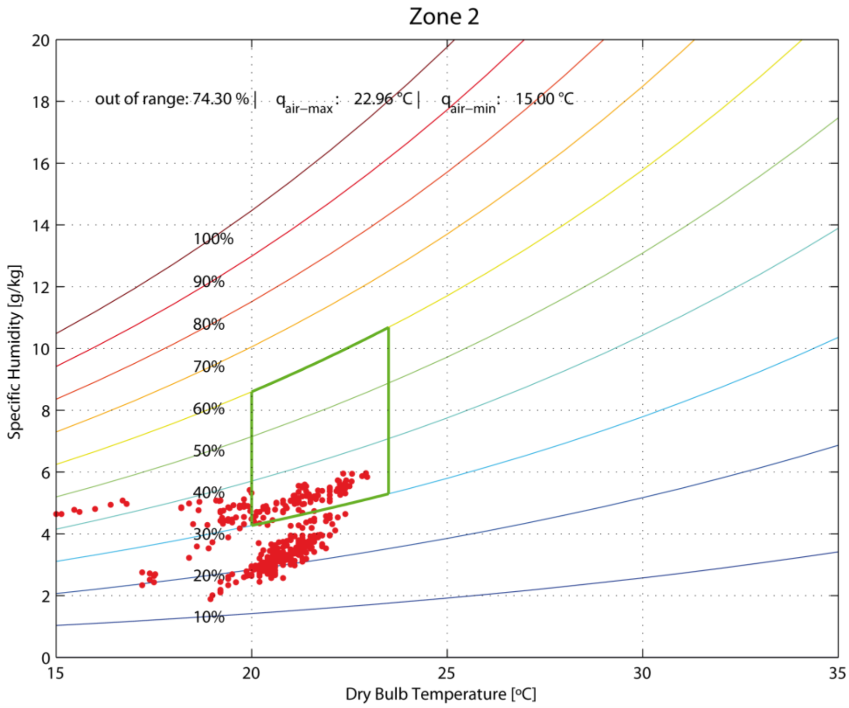

Figure 46. Psychrometric chart: thermal comfort zone, relative humidity, and internal temperature in office (zone 2) on occupied hours in the measured period from 5th November 2012 to 31st January 2013.

According to this diagram, 74 % of measurements were recorded outside the comfort zone. The outliers imply a very dry air inside this area. Most measurements were recorded with values between 10 and 40 % relative humidity. The temperature stayed mainly in the comfort zone, although some values were measured below the required minimum limit of 20 °C.

The adjacent seminar room at the east side of the building showed comparable results (Figure 63, Appendix). Relative humidity was mostly measured about 40 % and less. Temperature was recorded mainly in the comfort zone, but with outliers down to 15 °C. As a result, 69 % of the measured values were out of the comfort zone.

Thermal comfort in the kitchen differs significantly from the area around the office at NAT. Figure 47 shows the psychrometric chart of the kitchen for the measuring period as above mentioned.

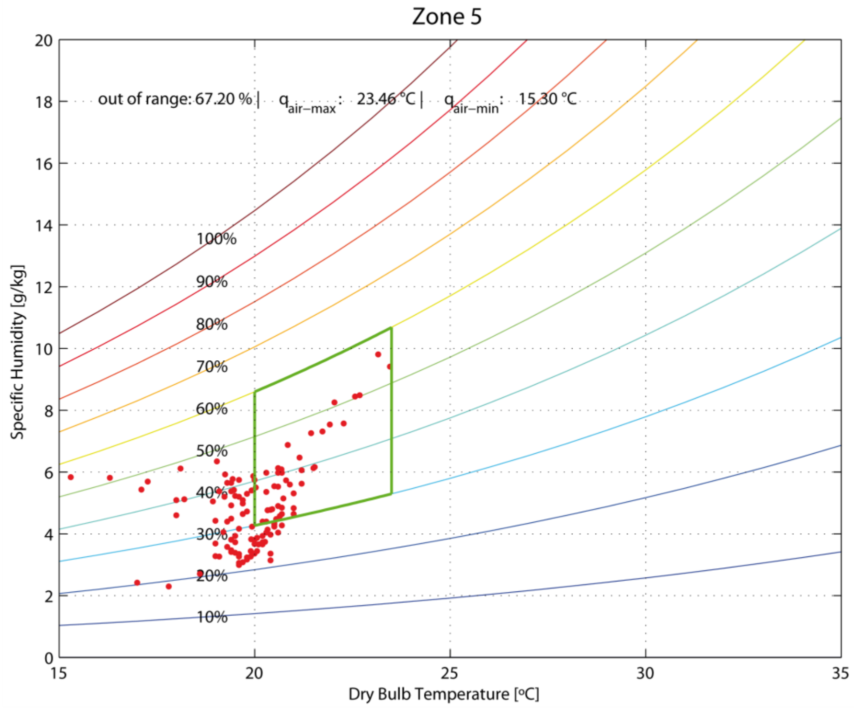

Figure 47. Psychrometric chart: thermal comfort zone, relative humidity, and internal temperature in the kitchen (zone 5) for the measured period from 5th November 2012 to 31st January 2013.

The relative humidity reached almost the upper limit of the comfort zone of 60 % on certain days. This was caused by cooking and high occupancy. Measurements comparable to the office area were recorded and outliers dominate the result. Low temperature and low relative humidity values lead to 67 % of measurements situated out of the comfort zone. This phenomenon is to be seen in any measured zone at NAT for this observation period. Aside the dry air in most of NAT's zones, thermal comfort can be stated as satisfactory in this building.

Frequent door openings due to high occupancy might have caused increased infiltration and air exchange. Consequently, the relative humidity decreased.

Warm air can take more water than cold air (WDP 2006). With an outdoor temperature range from -5 to 11 °C during the measuring period, the maximum specific humidity in the air could reach a maximum of 3 - 8 g (Mollier diagram). After ventilation, this cold and dry air from the outside was heated up in the building. Consequently the air inside NAT was dry and contained low relative humidity. Air exchange can occur either deliberately by opening windows, for instance, or unconsciously caused by leakages in the building envelope.

Infiltration

Monitored data from the 23rd September 2012 were used in order to calculate the infiltration rate at NAT. Both requirements were fulfilled in this period: absence of occupants and decline of CO_2 concentration. Figure 48 illustrates instancing CO_2 decline in zone 1 at a certain time span. Based on occupancy and CO_2 concentration measurements, infiltration rates were calculated for each zone on this specific day (Table 25).

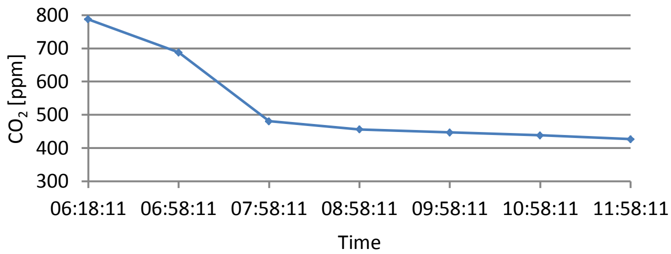

Figure 48. CO_2 concentration decay in zone 1 with related time stamps on the 23rd September 2012.

Table 25. Infiltration rate (ACH) [h^{-1}] per zone at NAT on the 23rd September 2012.

Zone	1	2	4	5	6	7
ACH	0.5	0.3	0.4	0.5	0.5	0.3

The Austrian standard ÖNORM B 8110-5 (2010) recommends 0.4 ACH (air changes per hour) for residential buildings. Results of infiltration are close to this value; hence imply tight building envelope, construction elements and windows. Nevertheless, the infiltration exceeds this limit in certain zones (Table 25). High infiltration causes high heat losses, and thus increases the heating demand.

This proposed calculation method is limited to evaluating the infiltration of a building during non-occupied periods. It is simplified with respect to one specific day. Though, it implies a first approximation towards heat losses through infiltration for a certain period. These findings have built the starting point to create an initial thermal performance simulation model.

4.2.3 Thermal Energy

Provision of Heat by Burning Pellets

A significant increase of the energy provided by the pellet furnace was observed on the 5th November 2012. The power ascended from almost zero to more than 20 kW, and stayed at this level until it decreased to a value of 6 kW. Thus, the start of the burning pellets process to support the heating system was ascertained on this date.

To put this in climatic context, the outdoor air temperature was considered: With begin of November 2012 it was recorded with 0° C. Heating days were determined with an outdoor temperature less than 12 °C (OIB RL6 2011). Thus, the heating had been provided by the solar thermal collector system until the pellet burner started to work.

The amount of energy provided by burning pellets was calculated per month for the observation period November 2012 to January 2013. Total heat provided by the pellet furnace and conducted to each floor heating circle was metered and listed in Table 26.

Table 26. Monthly sum of energy [kWh] provided by the pellet furnace and heat conducted to the floor heating circles ground floor and first floor.

	Pellet furnace	First floor	Ground floor
Nov 12	3724	526	1519
Dec 12	5356	823	2544
Jan 13	5279	896	2762
Σ	14359	2244	6825

According to Table 26, most of the heat provided by the pellet furnace was conducted to the ground floor heating cycle. One-third of the energy was required for heating in the first floor. Figure 49 opposes the distribution of heat in the building proportionately.

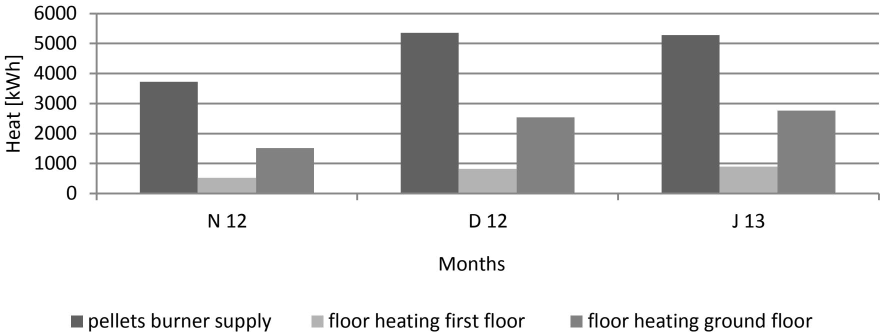

Figure 49. Monthly sum of heat [kWh] provided by pellet burner and heat distributed to floor heating cycles in ground floor and first floor.

The difference between the sum of heat led to the floor heating circles and the overall provision by the pellet burner has to be noted: One part was used for the warm water supply, another described heat losses of the system.

According to these measurements (Table 26), the energy demand by burning pellets per square meter in the considered period was of 44 kWh.m^{-2}. This result for a period of three months seems high compared to annual heating demands of historical data analysis. Increased warm water needs and heating demand due to raised occupancy explained this result.

NAT's administration confirmed this assumption in a meeting: In contrast to years prior to the monitoring period, also the winter months were determined by the presence of school classes. Consequently, heating was required to a greater extent to keep a comfortable indoor temperature of around 20°C. Moreover, warm water need augmented. As a result, the thermal energy demand increased.

Provision of Thermal Energy by the Solar Collector System

Figure 50 shows the daily amount of solar radiation (blue) and heat generated by NAT's solar thermal collectors (yellow) for the period from 20th September 2012 to the 20th January 2013.

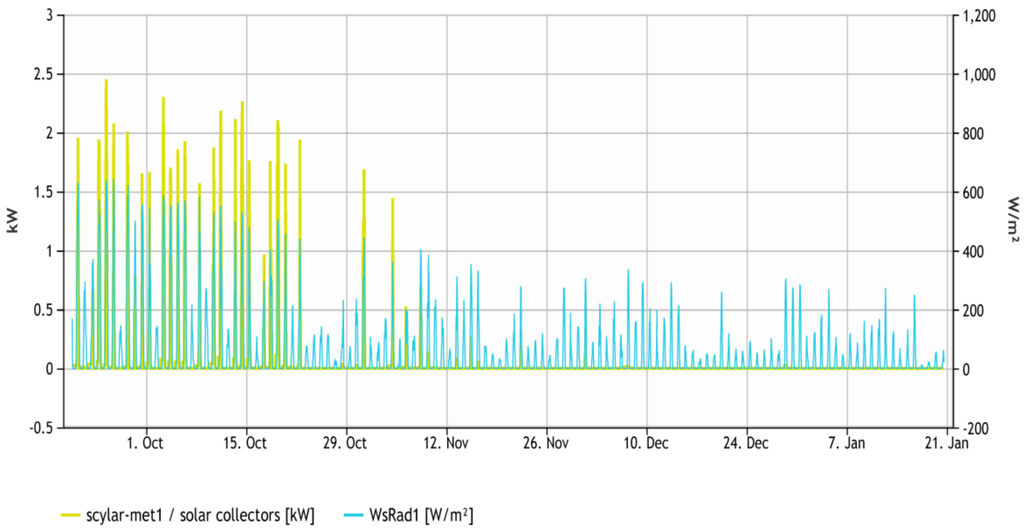

Figure 50. Solar radiation at NAT [W.m^{-2}] (blue) and heat produced by solar collectors [kW] (yellow) per day for the period from 20th September 2012 to the 20th January 2013.

This illustration shows constant energy generation by the solar thermal collector system until the 20th October 2012. At this time, a significant reduction of the solar radiation was noticed and solar gains were not recorded anymore.

Highest values of energy generation and solar radiation were measured in October 2012. Compared to these values, the energy gains during the winter months November 2012 to January 2013 were rare. Due to low energy provision by the solar thermal collectors in the winter period, an additional heating source had to supply the building with thermal energy. This resulted in the aforementioned start of the pellet furnace heating on the 5th November 2012.

Efficiency of the Thermal Collector System

The relation of solar radiation at NAT and the heat produced by the solar collectors informed about the efficiency of the system. Table 27 lists the results in percent for the measured period.

Table 27. Ratio [%] of recorded energy generated by the collectors to the incoming solar radiation at NAT for the period October 2012 to January 2013.

Month	Oct 12	Nov 12	Dec 12	Jan 13
%	4.1	0.7	0.1	0.5

According to the decrease of solar radiation, the energy output of the collector system and consequently the system's efficiency is significantly low in the winter period. Compared to October 2012, the efficiency of the system yielded one third only in winter months.

Conclusively, the amount of solar gains was compared to the energy required by burning pellets. The ratio of these values informs about the energy quantity, the solar thermal system could cover for a certain period. Due to low energy generation in winter, the solar collector system covered 2 % in November 2012, 0 % in December 2012, and 1 % in January 2013.

Warm Water Demand

Heat provided by the pellet furnace and the solar thermal collectors is used to warm domestic water at NAT, too. Table 28 lists the amount of warm water needed per month and the thermal energy used to heat it. NAT's energy requirements for domestic hot water related to gross area and day are listed.

Table 28. Monthly warm water demand [l] at NAT, required heat for warm water [kWh], and heat related to gross area and day [Wh. $m^{-2}.d^{-1}$] from October 2012 to January 2013.

Month	Oct 12	Nov 12	Dec 12	Jan 13
Water [l]	34	269	37	74
Heat [kWh]	28	375	142	130
Heat [Wh. $m^{-2}.d^{-1}$]	3	37	14	13

According to the Austrian standard ÖNORM B 8110-5 (2010), a single-family house needs 35 Wh.$m^{-2}.d^{-1}$, a multifamily residence 70 Wh.$m^{-2}.d^{-1}$. In comparison, the amount of thermal energy required to warm domestic hot water at NAT was very low. In November 2012, recorded measurements came near the guiding value for single-family houses. The amount measured in the other months implied less warm water demand. In order to explain the requirements stated, these results were related to occupancy conditions. As aforementioned, in November 2012 highest occupancy was recorded in the observation period and thus explains the increased warm water demand in November compared to the other months.

Heating - Relation between Pellet Furnace and Solar Collector System

During the analysis procedure, a conspicuous performance was noticed regarding the measurements illustrated on the webpage (Schuß 2013). On the 26th January 2013, the pellet furnace reduced its work. It descended the power significantly and stopped working two days later on the 28th January 2013. First, on the 8th February 2013 it started firing pellets again with a constant power of 5 kW. A remarkable energy feed-in from the solar collectors was noticed during the period from 30th January to 9th February 2013. The responsible meter counted a feed-in of around 1 kWh. This surveillance indicated a close relationship between the pellet burner and the solar thermal system. The leading water temperatures have to be considered in detail to explain this occurrence.

With the turn down of the pellets heating, the water temperature in the system decreased significantly. It declined to a value of 25 °C, whereas it had been recorded with 75 °C before. Figure 51 illustrates the temperature trend of the circulating water in the heating system during this period.

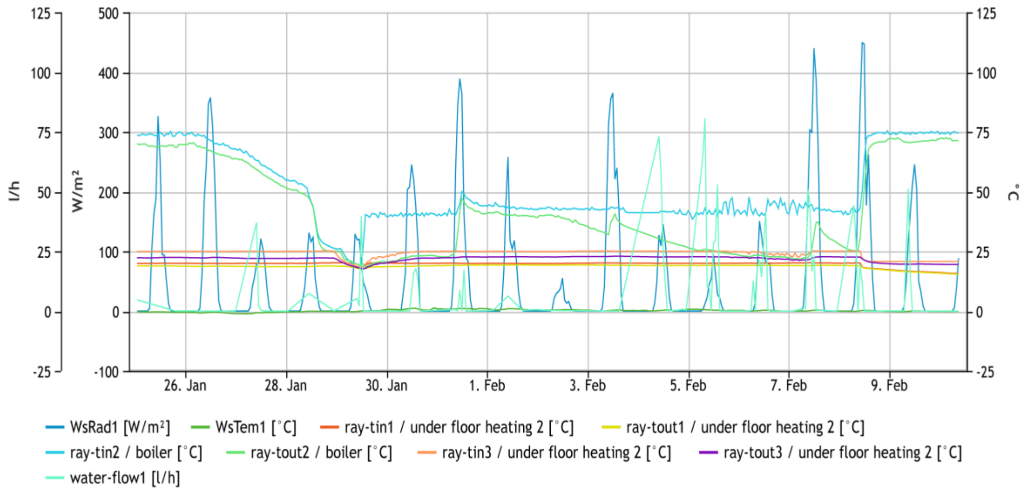

Figure 51. Measurements of global radiation [$W.m^{-2}$] (WsRad1), outdoor air temperature [°C] (WsTem1), water temperature [°C] (ray-tin2) and water flow [$l.h^{-1}$] (water-flow1) within the heating system from 26th January to 9th February 2013.

At the exact time of this occurrence, energy generated by the solar collectors was led to the heating system. The collectors receive a certain amount of exogenous heat (e.g. solar radiation) that warms the liquid in the pipes. The moment, this temperature exceeds the one in the circulating system, the heat generated is transported to the storage tank. There is no transfer, if the temperature in the tank is in excess of the incoming one. Consequently, with the decline of the temperature ruled by the heat from the pellet burner, the temperature in the reservoir decreased as well. Due to this lower temperature and incoming solar radiation, the solar collectors fed the heating system. Figure 52 shows trends of incoming solar radiation, energy generated by the collectors, and circulating water temperatures.

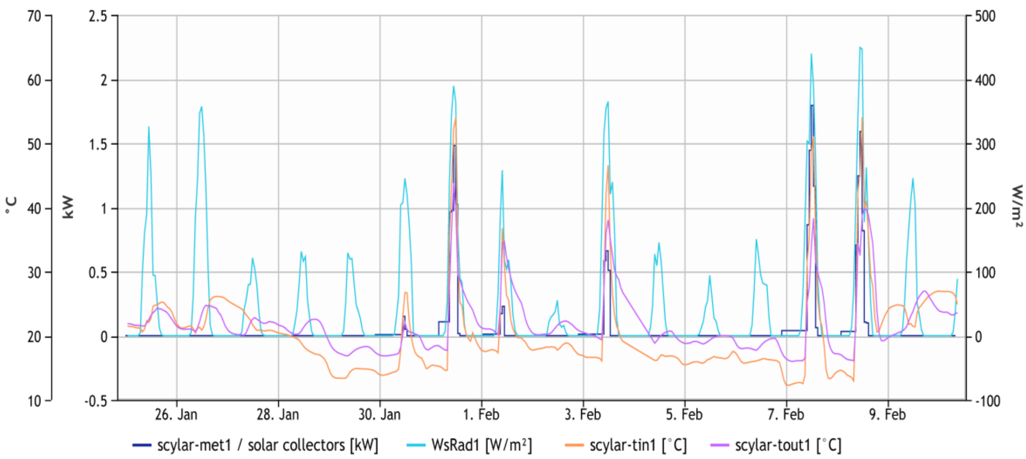

Figure 52. Incoming solar radiation [W.m^{-1}] (WsRad1), generated energy [kW] (scylar-met1), temperature [°C] of circulating water entering (scylar-tin1) and exiting (scylar-tout1) the system from 26th January to 9th February 2013.

Conclusively, the usual temperature in the storage tank is too high to receive heat from the solar thermal system. In order to use solar energy, the temperature in the circulating system has to be kept on a low temperature level.

For a healthy use of warm water, legionella have to be devitalized in heating up the water to 60 - 70 °C (UBA 2011). The storage tank combined of heating and warm water supply causes a total heating of the reservoir. Consequently, the water is heated to an average temperature of 70 - 75 °C. The solar collectors can hardly reach this temperature; hence the feed-in is rare during the work of the pellet burner.

One solution to support the usage of solar energy might be the separation of warm water and heating system. The reservoir for the heating supply could be kept on a maximum temperature of 30 °C. Supply for the low level under floor heating is sufficient and solar gains could feed the system. Conclusively, a minor part has to be heated up for the warm water provision and would reduce the energy use.

Thermal Energy Distribution

As recent measurement analysis showed, the heating support by the solar system is insignificant during the observation period October 2012 to January 2013. Thus, thermal energy was provided by burning pellets. Figure 53 shows heat requiring systems at NAT and the amount of energy used in percent for the period October 2012 to January 2013. The overall amount of heat generated by burning pellets in this period is set to 1.

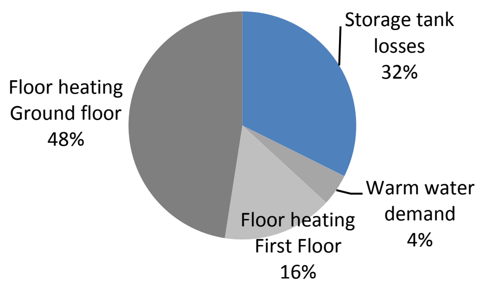

Figure 53. Amount of energy required by each system at NAT for the period October 2012 to January 2013.

According to Figure 53, the floor heating in the first floor was supplied with one third of the heat required in the ground floor. A huge amount of heat transferred from the storage tank is demonstrative in Figure 53. The reservoir is heated up to supply the floor heating circles and the warm water distribution. Furthermore, it emits heat as well. The heat emitted from the tank to the surrounding is counted at about 32 %.

4.2.4 Electricity

Electricity Use and Energy Generation by Photovoltaic Panels (PV)

Table 29 summarizes electricity generation by the system, overall use, and the intake from local grid for the period October 2012 to January 2013.

Table 29. Electricity at NAT [kWh] taken from local grid (G), fed-in to grid (F), produced by PV (P), and overall use (U) per month from October 2012 to January 2013.

Month	G	F	P	U
Oct 12	16389	116	1185	17458
Nov 12	18413	26	-	18413
Dec 12	17928	2	-	17928
Jan 13	17467	13	39	17494

Due to more intense solar radiation in October 2012, the energy generation was in excess for the following winter months. Electricity generated by PV counted 7 % of the overall use in October 2012 according to Table 29. Measured values for the winter months were close to 0 %. The electricity use per month was recorded with an average of 17700 kWh. Monthly sums showed a maximum use in November 2012, due to increased occupancy and consequently higher use of electronic devices such as dishwasher, computers, oven, etc. The percentage of renewable energy used for electricity provision accounts for 2 % in this period.

Prior analysis of solar radiation at NAT for the year 2012 showed maximum records in the summer time, especially in July. In order to analyze trends of solar radiation and electricity generation one representative day was chosen. The 3rd July 2012 was recorded with maximum outdoor temperature out of the entire measured period and represented average solar radiation values per day. Figure 54 shows the relation of radiation and energy generation on this specific day. The electricity generation was put in relation to the incoming solar radiation and the overall panel area of 78.6 m^{-2}.

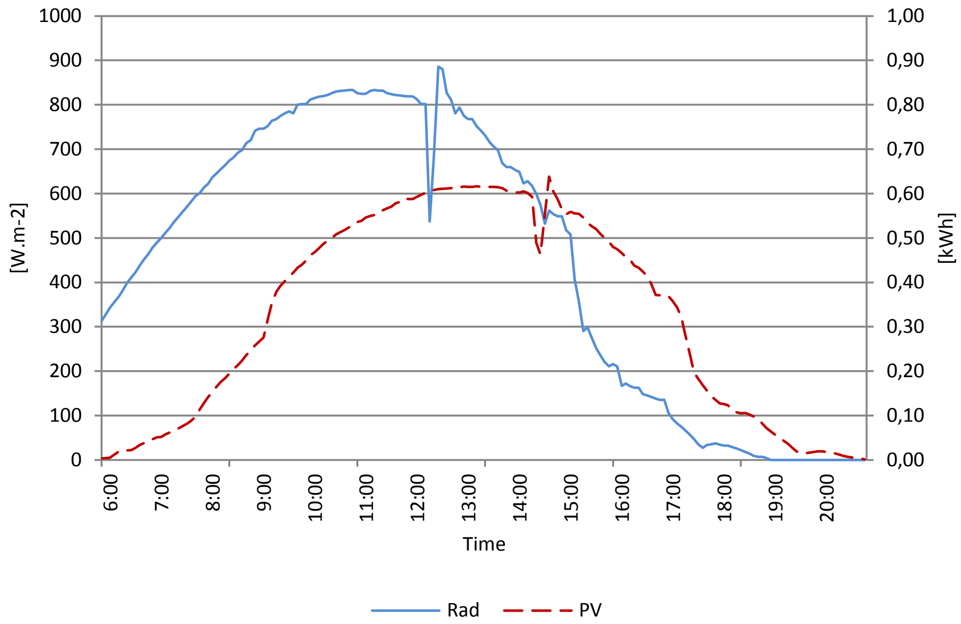

Figure 54. Solar radiation (Rad) [$W.m^{-2}$] and electricity generation (PV) [kWh] at NAT on the 3rd July 2012.

A peak was recorded with a value of 886 $W.m^{-2}$ at noon (UTC). Compared to the area of photovoltaic panels at NAT, the power generated counted 9.1 kW on this day. The installer company announced a peak power value of 10 kWp for this system at NAT. According to this information, the measured power on this representative day approached already this value. This power was converted to an energy amount of 58.5 kWh. The sharp decline of the measured solar radiation depicted in the graph around noon (Figure 54) assumable due to passing clouds or device irritation at the weather station. The electricity demand was measured with 7.5 kWh on this day.

Efficiency of the System

The efficiency of the photovoltaic panel system was stated for October 2012. Table 30 summarizes the area of the PV system, the incoming solar radiation, the electricity generated, and the resulting efficiency of the system for October 2012.

Table 30. Area of PV panels (A), solar radiation (SR), electricity generated (P), and efficiency of the system [%] at NAT for October 2012.

A [m^2]	SR [$W.m^{-2}$]	P [kWh]	E
29	619703	1185	7 %

The PV system at NAT worked with an efficiency of 7 % in October 2012. The modules were announced with an efficiency of 14 % (BCE 2013). In order to achieve the maximum efficiency (based on optimal conditions, such as angle, radiation intensity, covering, etc.) of the system, this value has to be multiplied with the efficiency factor (97%) of the inverter (Fronius 2013):

$$0.14 \times 0.97 = 0.1358.$$

This means, in an ideal situation with a solar radiation of 1000 $W.m^{-2}$, best orientation, and angle adjustments depending on the location, the system installed at NAT could yield an efficiency of 13.58 %.

On the 3rd July 2012, an efficiency of 11 % was recorded. This is almost 80 % of the maximum (13.58 %) output of the system. In October 2012 the system worked with 52 % of the maximum.

4.4 Building Performance Evaluation

4.4.1 Annual Thermal Balance

The input parameters for the annual thermal balance of NAT for the year 2012 were calculated manually. In case of a necessary use of guiding values, information from different Austrian regulations was applied. The air change rate was assumed with 0.4 h^{-1} for residential buildings according to OIB Leitfaden 2 (1999). Table 31 summarizes the input parameters and lists the results of heat gains and losses as far as the heating demand. The resulting heating demand of 67 $kWh.m^{-2}.a^{-1}$ came close to the former measured value of historical data analysis.

Table 31. Input and output of annual thermal balance of NAT for 2012.

Name	Formula	Unit	Abbr.	Result
Heating days		[d]	Hd	190
Heating degree days (20/12)		[Kd]	HDD	3094
air change rate		[h^{-1}]	nL	0.4
area windows		[m^2]	Aw	66
area doors		[m^2]	Ad	8
reference value		[$W.m^{-2}$]	qi	3.75
Ventilation losses	$Q_V = 0.024 \cdot L_V \cdot HDD$	[$kWh.a^{-1}$]	QV	8688
Transmission losses	$Q_T = 0.024 \cdot L_T \cdot HDD$	[$kWh.a^{-1}$]	QT	29211
Internal gains	$Q_i = 0.024 \cdot q_i \cdot BGF_B \cdot HD$	[$kWh.a^{-1}$]	Qi	5814
Solar gains	$Q_s = \sum[I_j \cdot A_{gj} \cdot f_{sj} \cdot g_{wj}]$	[$kWh.a^{-1}$]	Qs	9470
Thermal balance	$Qh = (QT + QV) - \eta\ (Qi + Qs)$	[kWh.a-1]	Qh	22921
Heating demand		[$kWh.m^{-2}.a^{-1}$]		67

4.4.2 Energy Certificate

Generation of Energy Certificates According to Changing Requirements in Guidelines

Energy certificates were generated for seven different scenarios for NAT according to Austrian standards' chronology. The scenarios took into consideration the building prior to the refurbishment, according to minimal requirements of standards of different years, and to passive house characteristics. Table 32 lists the heating demand result of each scenario.

Table 32. Heating demand [kWh.m^{-2}.a^{-1}] of NAT in different scenarios.

Scenario	Description	Heating Demand
1	Prior to renovation	137
2	Minimal requirements of 1988	88
3	NAT refurbished	65
4	Minimal requirements of 1996	66
5	Minimal requirements of today (2012)	55
6	As passive house without ventilation system	22
7	As passive house with ventilation system	9

According to the building classification of Austrian regulations (OIB RL 6 2011), NAT refurbished was ranged in group C with a heating demand of 65 kWh.m^{-2}.a^{-1}. In comparison, as a passive house with a ventilation system the building was marked as A++. In case of residential use only, NAT would be classified as a low-energy building (ÖNORM B 8110-1 2011). However, the combined use as office and residence has to be considered, too. Therefore, NAT cannot be nominated as an energy-saving building from today's point of view. At the time of its refurbishment though, NAT's heating demand exceeded the standard requirements.

To report accurately about the heat flow in the building, heat gains and losses calculated by the software were considered. Internal and solar heat gains and heat losses due to ventilation and transmission are depicted in Figure 55 for each scenario.

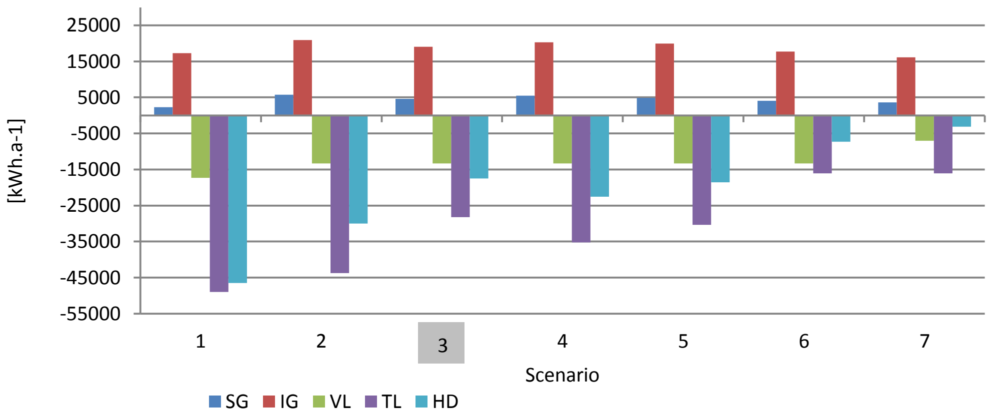

Figure 55. Solar gains (SG), internal gains (IG), ventilation losses (VL), transmission losses (TL), and heating load (HD) in [kWh.a^{-1}] for each scenario of NAT.

Transmission losses and heating demand decreased significantly from scenario 1 to 7. This implies an improvement of the building tightness due to lower U-values of the building elements. Ventilation losses remained on the same level with manual ventilation system in scenarios 2 – 6. The installation of an automatic ventilation system in scenario 7 reduced the heat losses by 47 % in passive house construction characteristics.

Influences of Different Parameter Settings on the Energy Certificate Results

Different assumptions were made in order to detect the sensitivity of the heating demand results according to input parameters. Therefore, the former scenario of NAT refurbished was set as the initial case. Based on these settings, modifications were adjusted in scenario 1 to 5. Table 33 informs about the different inputs to the software in each scenario. Figure 56 illustrates the heating demand results of each scenario.

Table 33. Input parameters to calculate energy certificates for different scenarios at NAT.

Scenario	Initial case:	Modification:								
	NAT refurbished	1	2a	2b	3a	3b	4a	4b	5a	5b
Residential building	No	Yes	Yes	No	Yes	No	Yes	No	Yes	No
Period	Year	Year	Oct-Jan	Oct-Jan	Year	Year	Year	Year	Year	Year
Schedule	Daily	Daily	Daily	Daily	Week	Week	Office	Office	NAT	NAT
ACH [h^{-1}]	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.7	0.4	0.4
HD [$kWh.m^{-2}.a^{-1}$]	65	121	132	43	126	56	125	64	129	56

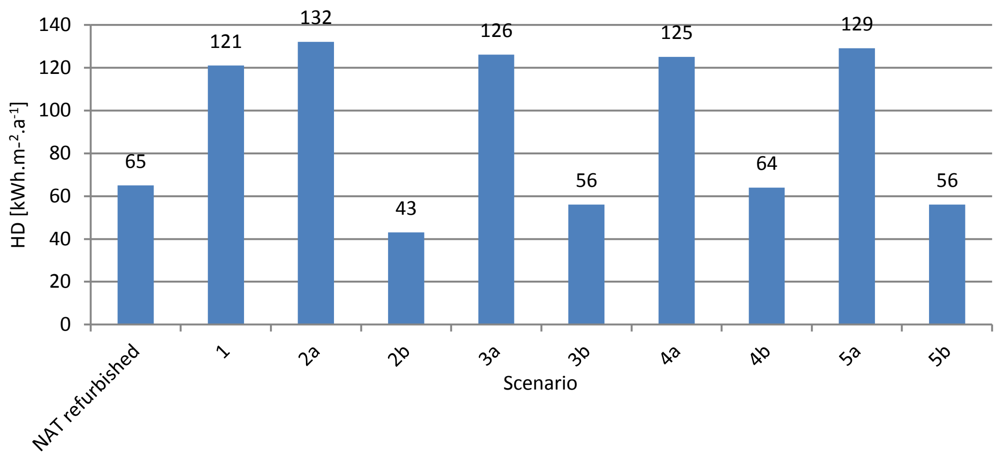

Figure 56. Heating demand [$kWh.m^{-2}.a^{-1}$] of NAT refurbished and of modified scenarios.

Figure 56 shows a clear increase of the heating demand in cases of residential use. This accounts for permanent occupancy and consequently more energy required during this time. Scenario 4 deals with office conditions such as appropriate occupancy adjustments and increased air change rate. Due to the results of heating demand in different scenarios, the factors of most influence can be stated as usage characteristics and air change rate. The subsequent change in the input parameter settings for the air change rate from 0.5 to 0.7 h^{-1} caused a heating demand increase of 13% from scenario 3 to 4.

Scenario 2 was calculated according to the measuring period of the monitoring system and meets the calculated heating demand closely. Figure 57 shows the results of heating demand, solar gains, internal gains, ventilation losses, and transmission losses.

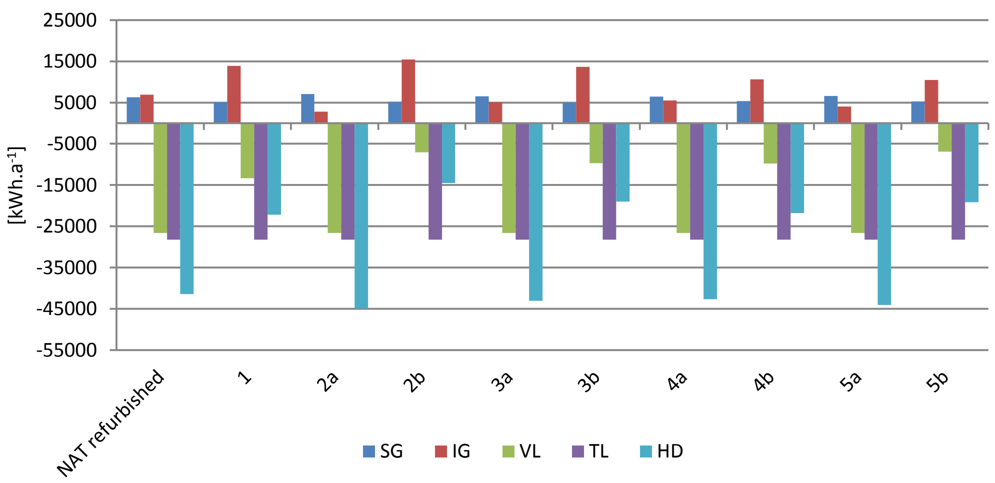

Figure 57. Solar gains (SG), internal gains (IG), ventilation losses (VL), transmission losses (TL), and heating demand (HD) in [$kWh.a^{-1}$] for each scenario of NAT in different performance cases.

Due to different parameters in the formula for calculating the ventilation conditions, the heat losses by ventilation vary significantly. This influences the results of the heating demand. In the case calculated for residential use, the ventilation is applied to 24 hours per day. Thus, the ventilation losses are higher in this scenario compared to the office case. Then, the ventilation is considered for office hours only and results in less heat losses.

Because of the changed parameters in the calculation process, the air change rate has a significant influence on the results. Internal heat gains and losses by ventilation vary accordingly. In case of high ventilation losses (residential building), the internal gains stay low in comparison to non-residential use. In addition, the heating demand increases in performance calculations with residential adjustments.

The energy certificate has to be understood as an approximation to find the heating demand as a standardized output. If a building is defined clearly as either residential or non-residential use, the energy certificate provides information about heat provision and usage. In case of NAT, the use is combined of part time residential, office, and hotel characteristics. The adjustments and consequently the results of the energy certificate can only approach the factual energy need.

4.4.3 Thermal Simulation

In order to find the most influential factor on the energy balance, eight different scenarios were calculated with a dynamic simulation tool. The influence of occupancy, temperature, and infiltration was examined. Figure 58 shows the resulting internal heat gains and losses and the overall heating demand per square meter and year. Table 34 summarizes the heating demand of each scenario.

Figure 58. Internal gains (IG), solar gains (SG), ventilation losss (VL), transmission losses (TL) in [kWh.a^{-1}] and according heating demand (HD) [kWh.m^{-2}.a^{-1}] of simulation scenarios.

Table 34. Heating demand (HD) [$kWh.m^{-2}.a^{-1}$] of simulation scenarios.

Scenario	SO	SF	M1	M2	M3	M4	M5	M6
HD [$kWh.m^{-2}.a^{-1}$]	84	39	29	29	29	28	45	46

The results show that internal gains are influenced mainly by heat emission due to occupancy and equipment. Consequently, the highest internal gains were simulated in the scenario with highest occupancy (SF) in the whole building. Standard office scenario (SO) was adjusted by the highest air change rate and resulted in the highest ventilation loss and heating demand compared to all other cases. Transmission losses increased with more occupancy and higher infiltration rate as shown in Figure 58.

Hence, the prior performed sensitivity analysis led to the assumption, that the air change rate is the most influential factor on the heating demand. As a consequence, the input of ACH was changed for consecutive simulations in order to come closer to the measured heating demand with the simulation. Therefore, the scenario based on measurements at NAT was used as the initial case. Table 35 informs about the different air change rates that were applied and the resulting heating demand.

Table 35. Air change rate (ACH) [h^{-1}] inputs and resulting heating demand (HD) [$kWh.m^{-2}.a^{-1}$] of simulations.

ACH	0.4	0.5	0.7	0.9	**1.0**	1.2	1.3	1.5
HD	28	30	34	39	41	45	47	52

Based on these findings, the air change rate at NAT was determined with 1.0 h^{-1}. In comparison to the standards, this value is higher than expected. It requires 0.4 h^{-1} for residential estates and 1.2 h^{-1} for sole office buildings. With an ACH of 0.4 h^{-1}, the heating demand of NAT could be reduced by 32%.

The building summary given by the tool EDSL TAS (EDSL 2012) after the simulation showed high temperatures during the summer period in the office. Overheating was stated for this area, assumably due to huge glazing percentage of this south orientated façade. Around 42 °C were simulated in the summer days. In order to support thermal comfort conditions, a suggestion is to install shades on this specific façade at least.

Energy Saving Potential at NAT

After the model was calibrated with the measurements at NAT, the heating demand was considered. In order to compare it to the recorded data, the same period had to be considered: November to January. Heat provision by burning pellets in the building was 44 $kWh.m^{-2}$. The same amount had to be reached with the model. Therefore, the infiltration was adjusted, as it was stated before as one of the main influencing factors. The same heating demand was finally reached with an infiltration rate of 1 h^{-1}. The standard requires 0.4 h^{-1} for residential estates and 1.2 h^{-1} for office buildings.

According to window construction applied in TAS (EDSL 2012), the resulting U-values have been 1.6 $W.m^{-2}.K^{-1}$ and 2.6 $W.m^{-2}.K^{-1}$ for the windows of NAT's simulation model. A reduction to 1.2 $W.m^{-2}.K^{-1}$ of all windows yielded a reduction of the heating demand by 7 %. Whereas an increase of the infiltration rate from 0.4 to 1.0 h^{-1} increased the heating demand by 32 %. Conclusively, the infiltration has a major influence on the heating demand and ought to be reduced in order to save energy in the building.

4.5 Summary of Findings

1. Does NAT meet thermal performance expectations according to standard requirements?

NAT aimed to represent an ideal construction with low energy demand. During the planning phase, a preliminary assumption of the heating demand had been announced with 38 $kWh.m^{-2}.a^{-1}$. In this calculation, uncertainties were to be assumed due to a new and experimental heating system at that time. Thus, heat losses in the system and the efficiency were not considered.
The energy certificate showed a heating demand of 65 $kWh.m^{-2}.a^{-1}$ and therefore less than the guidelines required after the renovation. Thus, the aim to create a low energy building was reached successfully at that point. However, the prior announced heating demand was not fulfilled. In comparison to today's standards, the building is classified in medium level (group C).
The energy use recorded by the monitoring system shows an increased demand compared to prior evaluation. However, in this case the energy provided by the pellet furnace and by the solar thermal collectors in order to heat the building and domestic hot water were considered. In this case, the energy demand increased by 33%.

2. Does the energy system of NAT, which is based in part on renewable energy sources, operate efficiently?

The efficiency of the solar thermal collector system was evaluated at 4 % in October 2012. During the winter months November to January, the efficiency decreased significantly. Regarding the whole year of 2011, the collectors supported the heating system by 54 % and met the prior assumed efficiency value closely.
In this research, an energy loss of 32 % was stated for the heating system. The heat radiated by the huge storage tank increases the ambient temperature

significantly. However, this thermal energy is not used efficiently. A separation of warm water and heating system in order to reduce the size of the reservoir might be useful. This could increase the efficiency of the whole system.
Furthermore, the adjustment of the heating system could be improved towards a more efficient energy use. A temperature decrease of the liquid circulating in the heating system allows the energy transformed by the solar collectors to be used in the building. Consequently, the efficiency of the solar thermal system would increase and the amount of pellets required for heating reduced.

3. Which parameters have the biggest influence on the building's thermal performance?

Based on the evaluation, the biggest influential factor on the heating demand was found to be the air change rate. A reduction from simulated actual values of 1.0 h^{-1} to 0.4 h^{-1} would yield a significant lower heating demand. In addition, the presence of people and the occupancy schedules have impacts on the energy needs of a building.

4. Does the building meet thermal comfort requirements?

According to the guidelines of ASHRAE standard 55 (ASHRAE 2004), thermal comfort conditions at NAT approach the requirements. There is dry climate in the building assessed due to heat emission radiated by the storage tank. Lower ambient temperatures in different zones refer either to unoccupied and therefore not heated zones or frequent door opening and leakages.

5. Monitoring and simulation: In which way did these methods support the thermal performance analysis presented?

Monitoring
The monitoring system was installed in order to analyze the actual thermal performance of the building. Real values of the whole monitoring period are available at any desired time. Thus, it enables an individual evaluation query of all recorded data. In addition, current situations can be observed and analyzed

directly in real time view. Extraordinary situations or user behavior can be detected within this monitoring and impacts on the stated thermal performance. Thus, potentials to improve the thermal performance and reduction of energy use were suggested. Furthermore, actual energy needs were stated. Influences on the heating demand were analyzed based on monitored data.

Although the monitoring system offers several benefits, the background has to be considered, too. In order to yield a precise analysis of the thermal performance, an extensive monitoring system is necessary. The more sensors are installed, the more accurate are the results. Thus, the financial aspect has to be covered. (Dense sensor grids are expensive.)

In order to start the analysis, data have to be collected first. Depending on the observation and analysis period desired, the examination cannot start instantly. Hence, data acquisition is time consuming with this analysis method.

Data handling has to be prepared and well planned. With the sensor installation and measurement delivery, a huge amount of data is available. This has to be collected, stored, and secured in an organized manner. Data administration and backups have to be controlled constantly in order to avoid data loss and gaps in the monitored data.

Simulation

The simulation tool used in this evaluation offered various flexible adjustment possibilities. Thus, different scenarios were created, analyzed, and compared with each other in order to state influential parameters on the heating demand. It supported the analysis in order to state the energy use in the building and to predict changes according to scenario variation. Hence, improvement possibilities for the thermal performance were investigated.

After the 3D model was created and calibrated, this analysis method of thermal simulation offers quick results and flexible operation modes.

In order to yield a precise thermal performance analysis, input parameters have to be complete and accurate. In most cases, not all values are available. Thus, impacts on the results of the analysis cannot be excluded. Consequently, the simulation has to be understood as an approximation to the real situation.

However, with these restrictions in mind, the results and input parameters can be adjusted in order to reach realistic outputs.
Furthermore, extraordinary user behavior is not considered. Schedules are to be assigned to different zones, but information input about characteristics is not possible.

Resume
Both methods cover advantages and restrictions in different manners. Actual values delivered by the monitoring system are preferable for a thermal performance analysis of an established building. Based on the available data, hypothetical scenarios can be created with the simulation tool in order to receive examination results quickly. Thus, a combination of both methods delivered the desired information in this case.

5. CONCLUSION AND FUTURE RESEARCH

5.1 Conclusion

This case study documented the performance of an energy efficient building, following the guidelines, that deploys regional and ecologically advantageous products, and incorporates systems to harness renewable energy. At the time of construction (1996), the requirements of the standards regarding low-energy buildings were exceeded. Today, almost two decades after the retrofit, the building still meets medium level performance classification.
The recent installation of an extensive monitoring system was a profitable investment. Information on energy use, thermal performance, indoor environment, and outdoor climate founded a broad analysis.

Collected data on carbon dioxide concentration, relative humidity, and internal temperature supported the objective evaluation of the indoor environment. With regard to NAT's indoor climate, this information, together with data on occupancy and outdoor conditions facilitated the generation of a clear picture.
Due to the fact that the analyzed period was in winter, the relative humidity levels were low. However, thermal comfort conditions were found to be acceptable. Moreover, indoor air quality (as represented via carbon dioxide concentration levels) was tended to be within recommended ranges most of the time in most zones of the building.

The monitoring system also supported the examination of the heating system and the energy use in the building. Tendencies of heating demand raise due to increased occupancy were stated. Other influential factors on the heating behavior and energy use were found to be the outdoor climate and the adjustment of the heating system. Furthermore it was stated that solar gains cover the heating demand already to a considerable extent. However, the percentage of the solar support of the heating system can be increased:

Therefore, suggestions to improve the efficiency of these installations were formulated.

Based on the information delivered by the monitoring system, a simulation model was created and calibrated for further investigations. A sensitivity analysis showed that the air change rate is one of the main influential factors on the energy use of the building. The analysis results indicate high infiltration values for NAT due to high leakage occurrence.

The results suggest that the aspirations behind the thermal retrofit of NAT toward achieving high energy efficiency did not undermine the primary function of the building toward provision of adequate indoor conditions for its occupants and visitors.

In view of the results of different analysis methods, the efforts of the renovation were beneficial for the building's performance, whereas the monitoring system proofed to be very useful support for the analysis.

5.2 Future Research

The monitoring system offers various analyses opportunities and further potential for energy efficiency and indoor climate improvement. Not all capabilities of this system have been exploited so far. The ongoing research shall further examine this building's performance in detail.

The analysis of the monitored winter period at NAT showed already important results about the building's performance. However, the efficiency of the heating system and the coverage of solar thermal energy can be stated more precise with a long-term observation. As solar radiation intensity is increased during the summer months, the energy generation by the photovoltaic panels has to be considered in addition to obtain data that would not only benefit system performance in NAT, but also installation and operation methods for future projects.

The calibration of the simulation model can be extended after a one year's measuring period in order to further analyze and interpret the building's actual energy and indoor environmental performance in the context of microclimatic dynamics and user behavior. The overheating tendencies simulated in the summer period can be proved by data from the monitoring system. Moreover, the way users interact with the system can be analyzed and suggestions to avoid uncomfortable situations in the building can be elaborated accordingly.

In order to state the ecologic and energy efficiency position of NAT in today's context, it might be meaningful to compare the building to a real estate built for the same targeted purpose.

Already performed improvement suggestions are to be monitored in order to examine the actual benefits, also in respect to show potentials for future projects.

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6.2 List of Figures

6.3 List of Tables

6.4 List of Equations

APPENDIX

I. Building Construction Characteristics

Table 36. Structural elements of NAT.

Building element	Thickness [m]	Components	Thickness [m]
External wall	0.46	Plaster inside lime cement	0.015
		Bricks HLZ	0.250
		Wood construction	0.040
		Cork insulating board	0.140
		Plaster	0.015
Ceiling	0.38	Tiles	0.020
		Screed	0.050
		Foil Hygrodiode 20 - classic	0.002
		Cork insulation	0.090
		Sand	0.040
		Cavitiy brick	0.160
		Plaster inside lime cement	0.015
Entry door	0.07	Spruce	0.070
External wall cellar	0.45	Cellar insulation	0.080
		Foil Hygrodiode 20 - classic	0.002
		Cellar bricks	0.350
		Plaster inside lime cement	0.015
Ground of celler	0.39	Screed	0.080
		Foil Hygrodiode 20 - classic	0.002
		Cellar insulation	0.030
		Leightweight aggregate	0.002
		Concrete	0.120
		Foil Hygrodiode 20 - classic	0.002
		Sand & gravel	0.150
Basement ceiling	0.26	Tiles	0.020
		Screed	0.050
		Foil Hygrodiode 20 - classic	0.002
		Cork insulation	0.030
		Concrete	0.160
Ground floor to ground	0.32	Tiles	0.020
		Screed	0.050
		Foil Hygrodiode 20 - classic	0.002
		Cork insulation	0.090
		Sand	0.040
		Concrete	0.120
Internal wall	0.13	Plaster inside lime cement	0.015
		Bricks HLZ	0.100
		Plaster inside lime cement	0.015
External wall dormer	0.36	Plaster inside lime cement	0.015
		Bricks HLZ	0.250
		Cork insulating board	0.075
		Plaster	0.015

Building element	**Thickness [m]**	**Components**	**Thickness [m]**
Roof dormer	0.27	Plaster	0.015
		Gypsum board	0.010
		Gypsum board	0.010
		Foil Hygrodiode 20 - classic	0.002
		Wood construction	0.100
		Flachshaus insulation	0.100
		Wood construction	0.025
		Tyvek Soft Antireflex roofing paper	0.002
		Wood construction	0.035
		Roof tile	0.070
Green roof	0.68	Plaster inside lime cement	0.015
		Cavitiy brick with concrete	0.210
		Foam glass	0.200
		Foil Hygrodiode 20 - classic	0.002
		Drainage stone	0.100
		Filter vlies	0.002
		Substrate	0.150
Roof seminar room east	0.74	Plaster inside lime cement	0.015
		Gypsum board	0.010
		Gypsum board	0.010
		Wood construction	0.025
		Foil Hygrodiode 20 - classic	0.002
		Wood construction	0.050
		Flachshaus insultation	0.250
		Wood construction	0.200
		Wood construction	0.025
		Tyvek Soft Antireflex roofing paper	0.002
		Wood construction	0.050
		Wood construction	0.035
		Roof tile	0.070
Roof seminar room west	0.72	Wood construction	0.050
		Wood construction	0.015
		Wood construction	0.200
		Wood construction	0.025
		Foil Hygrodiode 20 - classic	0.002
		Cork insulation	0.250
		Wood construction	0.025
		Tyvek Soft Antireflex roofing paper	0.002
		Wood construction	0.050
		Wood construction	0.030
		Roof tile	0.070
Stairs outside	0.30	Concrete	0.300
Window frame	0.06	Spruce	0.060
Window pane	0.02	Glass	0.004
		Argon	0.012
		Glass	0.004

Table 37. Building elements: Area, orientation, U-value.

Building element	**Area** [m²]	**NNW** 345°	**ENE** 69°	75°	**SSE** 165°	159°	**WSW** 249°	255°	**Horizontal**	**U-Value** [W.m⁻².K⁻¹]
External wall	211.54	96.87	11.70	18.49	32.19	-	52.29	-	-	0.20
Unheated against outside	47.26	5.58	5.95	25.14	10.59	-	-	-	-	-
Heated against unheated	37.17	-	-	32.17	5.00	-	-	-	-	-
Ceiling	-	-	-	-	-	-	-	-	-	0.29
Entry door	7.45	-	-	-	7.45	-	-	-	-	
External wall cellar	5.00	-	-	-	5.00	-	-	-	-	0.25
Ground celler	143.79	-	-	-	-	-	-	-	143.79	0.29
Basement ceiling	71.86	-	-	-	-	-	-	-	71.86	0.29
Unheated against basement	8.62	-	-	-	-	-	-	-	8.62	-
Ground floor to ground	98.57	-	-	-	-	-	-	-	98.57	0.28
Unheated against ground	10.60	-	-	-	-	-	-	-	10.60	-
Heated against unheated	45.27	-	-	-	-	45.27	-	-	-	-
External wall dormer	48.60	6.21	-	18.61	5.17	-	-	18.61	-	0.42
Roof dormer	54.06	5.17	-	22.29	4.31	-	-	22.29	-	0.41
Green roof	21.26	-	-	-	-	-	-	-	21.26	-
Roof seminar room east	162.65	87.34	-	-	75.31	-	-	-	-	0.17
Roof seminar room west	107.98	30.67	22.06	-	17.57	-	37.68	-	-	0.17
Stairs outside	5.51	-	-	-	5.51	-	-	-	-	-
∑ area	**1156.73**	-	-	-	-	-	-	-	-	-
∑ Window area	**65.94**	19.60	5.11	-	36.40	-	4.83	-	-	1.25

II. Technical Data Sheets of Sensors

Indoor Environment: Combined wireless sensor

CO_2/Temperature/rel.Humidity SR04 CO2 – Datasheet (Thermokon 2012)

Technology: EnOcean, Dolphin

Transmitting frequency: 868.3 MHz

Transmitting range: approx. 30m in buildings, approx. 300m

Power supply: 15-24VDC (±10%) or 24VAC (±10%) (SELV)

Power consumption: max. 1.5W / max.3.6VA

Clamps: terminal screw, max. 1.5mm^2, wire or braid

CO_2 Sensor: NDIR (non dispersive infrared)

Measuring range: CO_2: 0...2550ppm; Temp.: 0...51°C

Temp. Dependence: CO_2: <0,2% of Full Scale per °C

Accuracy @21°C: CO_2: typ. ±40ppm + 4% of reading

Temp.: Typical ±1K of full scale

Warm Up Time: < 2 minutes

Response Time: < 10 minutes

Stability CO_2: < 2% Full Scale over life of sensor (typ. lifetime 15 years)

Repeatability CO_2: <1% of Full Scale

Calibration interval: not required - see ABCLogic

Housing: Material ASA, colour pure white

Housing protection: IP30 according to EN60529

Ambient temperature: 0...+50°C, max. 85%rH no condensate

Weight: ca. 90g

Option rH:

Sensor: Integrated sensor for rel. humidity

Accuracy @21°C: Humidity:Typ. ±3% (between 20...80% rH)

Measuring range: 0...100%rH

Occupancy: Wireless Ceiling Multi Sensor 360° SR-MDS Solar – Datasheet (Thermokon 2012)

Technology: EnOcean, STM

Transmitting frequency: 868.3 MHz

Transmitting range: approx. 30m in buildings, approx. 300m upon free propagation

Movement detection: PIR "passive infrared"

Brightness detection: 0...512Lux

Measuring value detection: every 100 seconds

Sending interval: directly with movement detection
…every 100 seconds
if brightness changes >10Lux,
or with switching off the movement detector
…every 1000 seconds
if brightness changes <10Lux,
or if no movement is detected

Energy generator: Solar cell, internal goldcap, maintenance-free

Enclosure: PC V0, colour pearl white, similar to RAL1013

Protection: IP50 according to EN60529

Ambient temperature: 10…55°C

Transport: -10…65°C/ max. 70%rH, non-condensed

Weight : 120g

Heat: Compact Energy Meter Ray – Datasheet (Diehl 2012)

General

Temperature range °C 5 ... 90

Ambient operating temperature °C 0 ... 55

Ambient storage temperature °C -20 ... 55

Nominal pressure PN bar 16

Approval EN 1434 (22.52 / 00.02) / EC type examination certificate (DE-07-I004-PTB030)

Technical data

Nominal diameter DN mm 15

Nominal flow rate qp m^3/h 0.6

Maximum flow rate qs m^3/h 1.2

Minimum flow rate qi l/h 6

Starting flow rate l/h 1.5 - 2

Pressure loss at qp Δp mbar 243

Flow rate at 0.1 bar pressure loss m^3/h 0.385

Flow resistance coefficient Zeta 56.25

Temperature input

Max. temperature difference ΔΘ K +147

Min. temperature difference ΔΘ K +3

Starting temperature difference ΔΘ K +0.25

Absolute temperature measurement range Θ °C 0 ... 150

Supply voltage

Operating voltage UN VDC 3.0 (lithium battery)

Battery lifetime 12 years

Nominal power PN µW 30

Radio interface - specification

Frequency MHz 868.95

Protocol Real data (according EN 13757) or open metering

Transmission power mW 25

Transmission interval sec. 64

Communication BLUETOOTH OPTOHEAD and HYDRO-SET or IZAR@MOBILE

Volume- / energy pulse open collector

Max. frequency Hz 4

Max. input voltage V 30

Max. input current mA 100

Max. voltage drop at active

output V/mA 2/27

Max. current through inactive

output μA/V 5/30

Max. reverse voltage without

destroying outputs V 6

Pulse duration ms 125

Min. pulse break ms 125

Solar thermal colloectors: Scylar Int 8 – Datasheet (Diehl 2012)

Battery 3,6 VDC; A- cell: 11 years lifetime; 3,6 VDC; D-cell: 20 years lifetime

Power supply 24 VAC; 230 VAC / 0.15W

Input frequency volume impulse Max. 200 Hz; impulse duration > 3ms

Temperature input

Operating voltage mA Pt 100 peak < 8; rms < 0.015, Pt 500 peak < 2; rms < 0.012

Measuring cycle T s Mit Netzteil: 2 s; Batterie: A-Zelle: 16 s; D-Zelle: 4 s

Starting temperature difference ΔΘ K 0.125

Min. temperature difference ΔΘmin K 3

Max. temperature difference ΔΘmax K 177

Absolute temperature measurement range Θ °C -20 ... 190

Water: Single-Jet Meter Auqarius – Datasheet (Diehl 2012)

Length L mm 80

Nominal flowrate Q3 m^3/h 2.5

Starting flowrate l/h 12

Min. flowrate Q1 l/h 31

Transition flowrate Q2 l/h 50; Max. flowrate Q4 m^3/h 3.125

Electricity: Wireless Metering Interface SR-MI-HS – Datasheet (Thermokon 2012)

Power supply: 24VDC (±10%) or 24VAC (±10%)

Power consumption: typ. 0,2W / 0,4VA In case of shorting all S0 inputs: max. 1,6W / 3,2VA

Transmitting frequency: 868.3 Mhz

Transmitting range: approx. 30m in buildings, approx. 300m upon free propagation

Inputs: 3 S0-Interface inputs

Protection: IP20 according to EN 60529

Ambient temperature: 0...50°C

Humidity: 0...75%rH, non-condensing

Storage temperature: -20...60°C

Equipment Profile: A5-12-00

Weight: approx. 90g (without external antenna)

Weather: Wireless Vantage Pro2 station – Datasheet (Davis 2012)

Operating Temperature -40° to +150°F (-40° to +65°C)

Non-operating Temperature -40° to +158°F (-40° to +70°C)

Current Draw (ISS SIM only) 0.14 mA (average), 30 mA (peak) at 4 to 6 VDC

Solar Power Panel 0.5 Watts (ISS SIM), plus 0.75 Watts (Fan-Aspirated)

Battery (ISS SIM /Fan-Aspirated) CR-123 3-Volt Lithium cell / 2 - 1.2 Volt NiCad C-cells

Battery Life (3-Volt Lithium cell) 8 months without sunlight - greater than 2 years depending on solar charging

Battery Life (NiCad C-cells, Fan-Aspirated) 1 year

Wind Speed Sensor: Solid state magnetic sensor

Wind Direction Sensor: Wind vane with potentiometer

Rain Collector Type : Tipping bucket, 0.01" per tip (0.2 mm with metric rain adapter), 33.2 in2 (214 cm2)

Temperature Sensor Type: PN Junction Silicon Diode

Relative Humidity Sensor Type : Film capacitor element

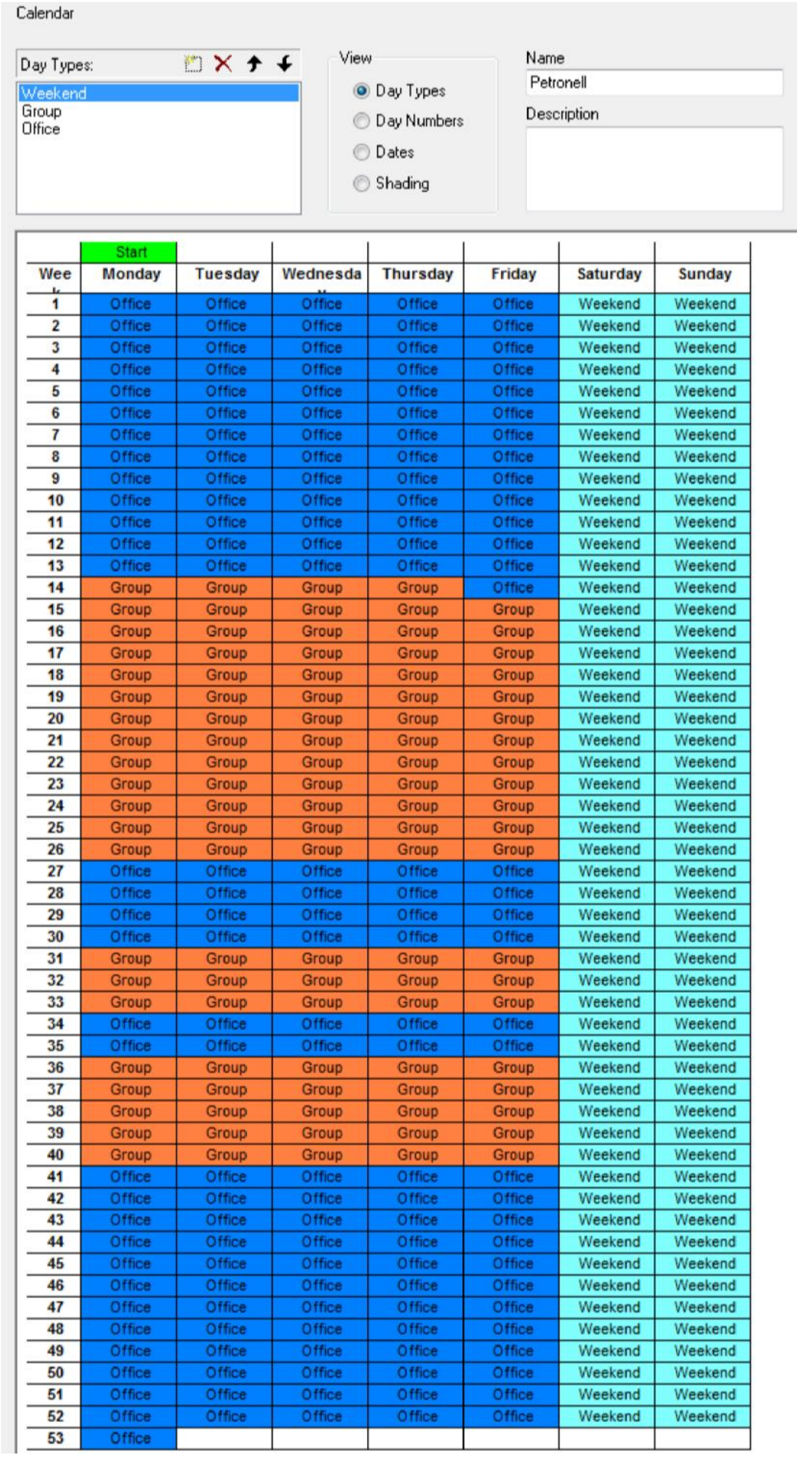
III. Building Performance Evaluation

Annual Balance Results

Table 38. Annual balance results.

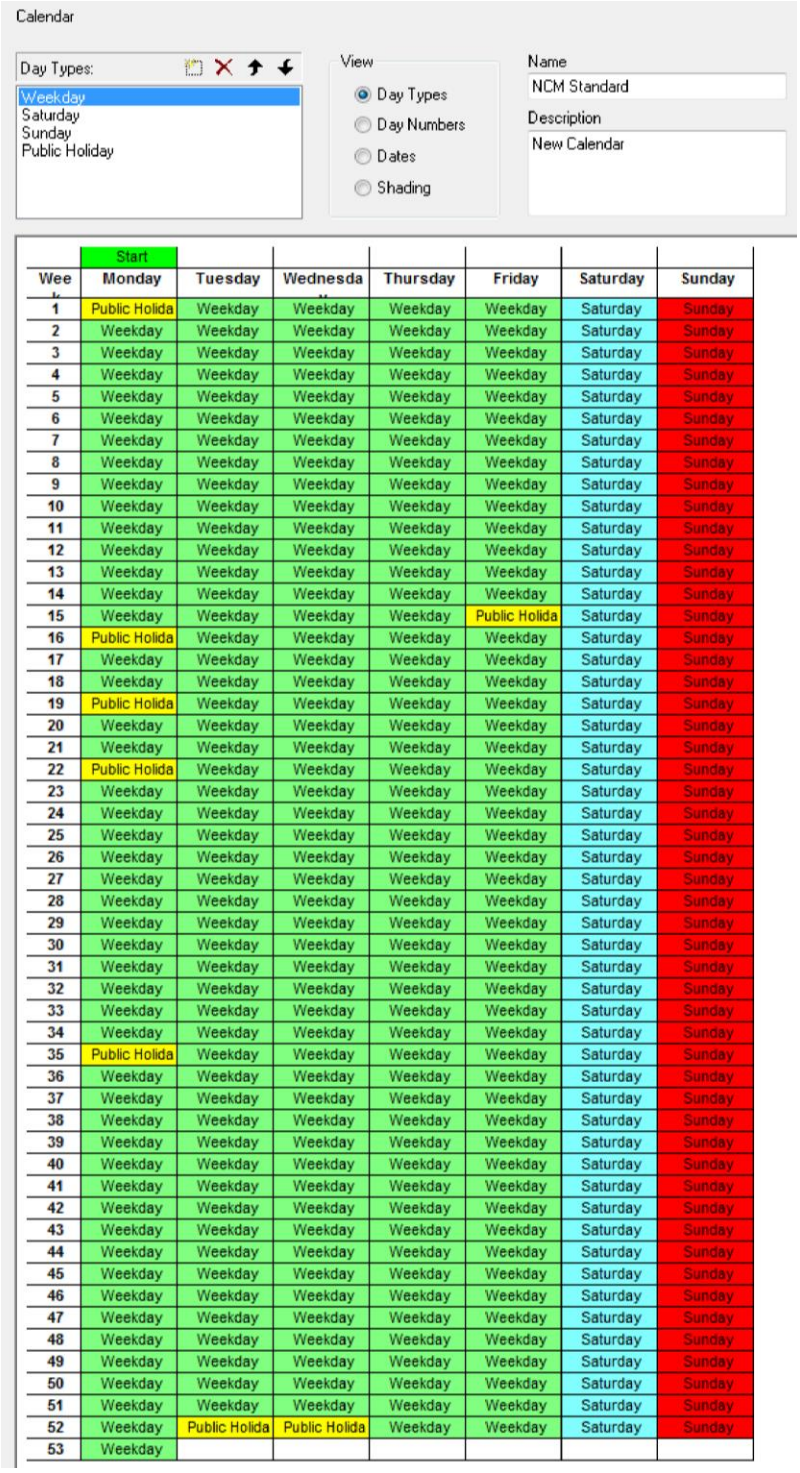
Name	Unit	Abbr.	Result
heated gross area (ground floor)	[m^2]	BGF_B	340.00
heated volume	[m^3]	V_B	886.37
Heating days	[d]	Hd	190.00
Heating degree days (20/12)	[Kd]	HDD	3094.00
Ventilation losses	[$kWh.a^{-1}$]	Q_V	8688.01
air change rate	[h^{-1}]	n_L	0.40
specific ventilation loss	[W]	P_1	0.10
heat loss coefficient for windows and doors	[$W.m^{-2}.K^{-1}$]	w_F	2.80
area windows	[m^2]	A_w	65.94
area doors	[m^2]	A_d	7.54
air change	[$W.K^{-1}$]	L_{V1}	87.75
leaky windows/doors	[$W.K^{-1}$]	L_{V2}	205.74
guide value envelope	[$W.K^{-1}$]	L_V	117.00
Transmission losses	[$kWh.a^{-1}$]	Q_T	29211.25
guide value envelope	[$W.K^{-1}$]	L_T	393.39
Internal gains	[$kWh.a^{-1}$]	Q_i	5814.00
reference value	[$W.m^{-2}$]	q_i	3.75
Solar gains	[$kWh.a^{-1}$]	Q_s	9469.52
south			6822.60
north			1547.91
east			564.99
west			534.03
horizontal			0.00
sum of radiation per orientation	[$kWh.m^{-2}.a^{-1}$]	I_j	1294.00
south	[$kWh.m^{-2}.a^{-1}$]	I_s	356.00
north	[$kWh.m^{-2}.a^{-1}$]	I_n	150.00
east	[$kWh.m^{-2}.a^{-1}$]	I_e	210.00
west	[$kWh.m^{-2}.a^{-1}$]	I_w	210.00
horizontal	[$kWh.m^{-2}.a^{-1}$]	I_{ch}	368.00
area glazing per orientation	[m^2]	A_{gj}	
south	[m^2]		36.40
north	[m^2]		19.60
east	[m^2]		5.11
west	[m^2]		4.83
reduction factor shading		f_{sj}	
south			0.90
north			0.90
east			0.90
west			0.90
g-value			0.65
gw			0.59
Degree of utilization		η	0.98
Thermal balance	[$kWh.a^{-1}$]	Q_h	22921.41
Heating demand	[$kWh.m^{-2}.a^{-1}$]		67.42
Ratio heat gains to heat losses			0.40

Thermal Simulation Input Parameters



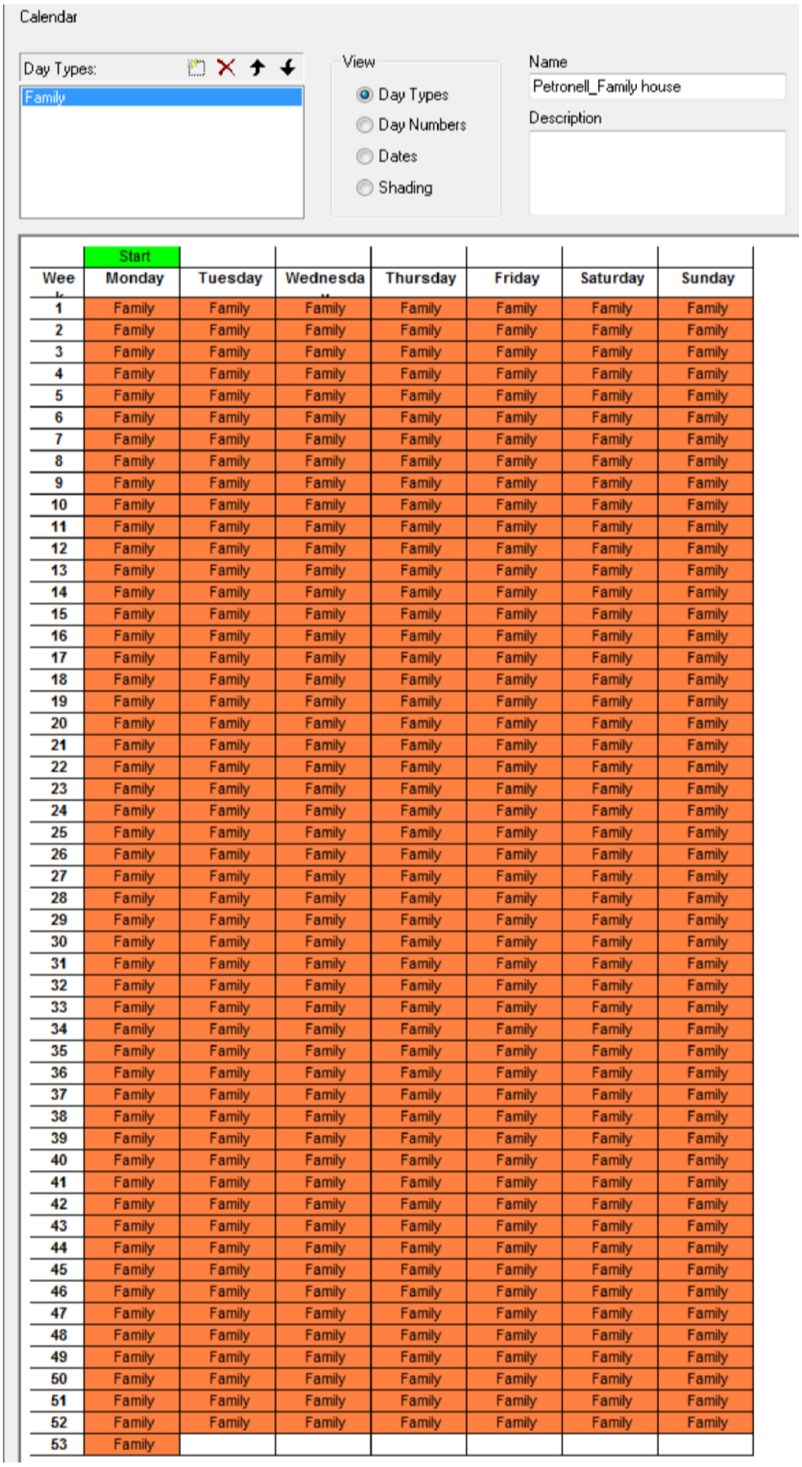
Wee	Start Monday	Tuesday	Wednesda	Thursday	Friday	Saturday	Sunday
1	Office	Office	Office	Office	Office	Weekend	Weekend
2	Office	Office	Office	Office	Office	Weekend	Weekend
3	Office	Office	Office	Office	Office	Weekend	Weekend
4	Office	Office	Office	Office	Office	Weekend	Weekend
5	Office	Office	Office	Office	Office	Weekend	Weekend
6	Office	Office	Office	Office	Office	Weekend	Weekend
7	Office	Office	Office	Office	Office	Weekend	Weekend
8	Office	Office	Office	Office	Office	Weekend	Weekend
9	Office	Office	Office	Office	Office	Weekend	Weekend
10	Office	Office	Office	Office	Office	Weekend	Weekend
11	Office	Office	Office	Office	Office	Weekend	Weekend
12	Office	Office	Office	Office	Office	Weekend	Weekend
13	Office	Office	Office	Office	Office	Weekend	Weekend
14	Group	Group	Group	Group	Office	Weekend	Weekend
15	Group	Group	Group	Group	Group	Weekend	Weekend
16	Group	Group	Group	Group	Group	Weekend	Weekend
17	Group	Group	Group	Group	Group	Weekend	Weekend
18	Group	Group	Group	Group	Group	Weekend	Weekend
19	Group	Group	Group	Group	Group	Weekend	Weekend
20	Group	Group	Group	Group	Group	Weekend	Weekend
21	Group	Group	Group	Group	Group	Weekend	Weekend
22	Group	Group	Group	Group	Group	Weekend	Weekend
23	Group	Group	Group	Group	Group	Weekend	Weekend
24	Group	Group	Group	Group	Group	Weekend	Weekend
25	Group	Group	Group	Group	Group	Weekend	Weekend
26	Group	Group	Group	Group	Group	Weekend	Weekend
27	Office	Office	Office	Office	Office	Weekend	Weekend
28	Office	Office	Office	Office	Office	Weekend	Weekend
29	Office	Office	Office	Office	Office	Weekend	Weekend
30	Office	Office	Office	Office	Office	Weekend	Weekend
31	Group	Group	Group	Group	Group	Weekend	Weekend
32	Group	Group	Group	Group	Group	Weekend	Weekend
33	Group	Group	Group	Group	Group	Weekend	Weekend
34	Office	Office	Office	Office	Office	Weekend	Weekend
35	Office	Office	Office	Office	Office	Weekend	Weekend
36	Group	Group	Group	Group	Group	Weekend	Weekend
37	Group	Group	Group	Group	Group	Weekend	Weekend
38	Group	Group	Group	Group	Group	Weekend	Weekend
39	Group	Group	Group	Group	Group	Weekend	Weekend
40	Group	Group	Group	Group	Group	Weekend	Weekend
41	Office	Office	Office	Office	Office	Weekend	Weekend
42	Office	Office	Office	Office	Office	Weekend	Weekend
43	Office	Office	Office	Office	Office	Weekend	Weekend
44	Office	Office	Office	Office	Office	Weekend	Weekend
45	Office	Office	Office	Office	Office	Weekend	Weekend
46	Office	Office	Office	Office	Office	Weekend	Weekend
47	Office	Office	Office	Office	Office	Weekend	Weekend
48	Office	Office	Office	Office	Office	Weekend	Weekend
49	Office	Office	Office	Office	Office	Weekend	Weekend
50	Office	Office	Office	Office	Office	Weekend	Weekend
51	Office	Office	Office	Office	Office	Weekend	Weekend
52	Office	Office	Office	Office	Office	Weekend	Weekend
53	Office						

Figure 59. Calendar of NAT in TAS simulation (EDSL 2012).



Wee	Monday	Tuesday	Wednesda	Thursday	Friday	Saturday	Sunday
1	Public Holida	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
2	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
3	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
4	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
5	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
6	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
7	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
8	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
9	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
10	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
11	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
12	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
13	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
14	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
15	Weekday	Weekday	Weekday	Weekday	Public Holida	Saturday	Sunday
16	Public Holida	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
17	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
18	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
19	Public Holida	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
20	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
21	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
22	Public Holida	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
23	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
24	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
25	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
26	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
27	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
28	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
29	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
30	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
31	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
32	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
33	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
34	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
35	Public Holida	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
36	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
37	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
38	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
39	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
40	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
41	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
42	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
43	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
44	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
45	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
46	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
47	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
48	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
49	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
50	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
51	Weekday	Weekday	Weekday	Weekday	Weekday	Saturday	Sunday
52	Weekday	Public Holida	Public Holida	Weekday	Weekday	Saturday	Sunday
53	Weekday						

Figure 60. Calendar of case SO in TAS simulation (EDSL 2012).



Wee	Start Monday	Tuesday	Wednesda	Thursday	Friday	Saturday	Sunday
1	Family	Family	Family	Family	Family	Family	Family
2	Family	Family	Family	Family	Family	Family	Family
3	Family	Family	Family	Family	Family	Family	Family
4	Family	Family	Family	Family	Family	Family	Family
5	Family	Family	Family	Family	Family	Family	Family
6	Family	Family	Family	Family	Family	Family	Family
7	Family	Family	Family	Family	Family	Family	Family
8	Family	Family	Family	Family	Family	Family	Family
9	Family	Family	Family	Family	Family	Family	Family
10	Family	Family	Family	Family	Family	Family	Family
11	Family	Family	Family	Family	Family	Family	Family
12	Family	Family	Family	Family	Family	Family	Family
13	Family	Family	Family	Family	Family	Family	Family
14	Family	Family	Family	Family	Family	Family	Family
15	Family	Family	Family	Family	Family	Family	Family
16	Family	Family	Family	Family	Family	Family	Family
17	Family	Family	Family	Family	Family	Family	Family
18	Family	Family	Family	Family	Family	Family	Family
19	Family	Family	Family	Family	Family	Family	Family
20	Family	Family	Family	Family	Family	Family	Family
21	Family	Family	Family	Family	Family	Family	Family
22	Family	Family	Family	Family	Family	Family	Family
23	Family	Family	Family	Family	Family	Family	Family
24	Family	Family	Family	Family	Family	Family	Family
25	Family	Family	Family	Family	Family	Family	Family
26	Family	Family	Family	Family	Family	Family	Family
27	Family	Family	Family	Family	Family	Family	Family
28	Family	Family	Family	Family	Family	Family	Family
29	Family	Family	Family	Family	Family	Family	Family
30	Family	Family	Family	Family	Family	Family	Family
31	Family	Family	Family	Family	Family	Family	Family
32	Family	Family	Family	Family	Family	Family	Family
33	Family	Family	Family	Family	Family	Family	Family
34	Family	Family	Family	Family	Family	Family	Family
35	Family	Family	Family	Family	Family	Family	Family
36	Family	Family	Family	Family	Family	Family	Family
37	Family	Family	Family	Family	Family	Family	Family
38	Family	Family	Family	Family	Family	Family	Family
39	Family	Family	Family	Family	Family	Family	Family
40	Family	Family	Family	Family	Family	Family	Family
41	Family	Family	Family	Family	Family	Family	Family
42	Family	Family	Family	Family	Family	Family	Family
43	Family	Family	Family	Family	Family	Family	Family
44	Family	Family	Family	Family	Family	Family	Family
45	Family	Family	Family	Family	Family	Family	Family
46	Family	Family	Family	Family	Family	Family	Family
47	Family	Family	Family	Family	Family	Family	Family
48	Family	Family	Family	Family	Family	Family	Family
49	Family	Family	Family	Family	Family	Family	Family
50	Family	Family	Family	Family	Family	Family	Family
51	Family	Family	Family	Family	Family	Family	Family
52	Family	Family	Family	Family	Family	Family	Family
53	Family						

Figure 61. Calendar of case SF in TAS simulation (EDSL 2012).

Thermal Simulation Output Paramters

Table 39. Simulation – sensitivity analysis – scenario results of heat gains and losses [kWh.a-1].

	SO	SF	M 1	M2	M3	M4	M5	M6
Q_s	25713	25713	25713	25713	25713	25713	25713	25713
Q_i	7074	10655	4048	4365	4891	4891	4048	4891
Q_V	28960	11692	7612	7702	7876	7515	8191	8531
Q_T	27376	32814	16970	28931	29118	29198	30521	31085
Q_h	27318	12607	9310	9322	9267	9082	14600	15027

IV. Monitoring Evaluation

Carbon dioxide concentration

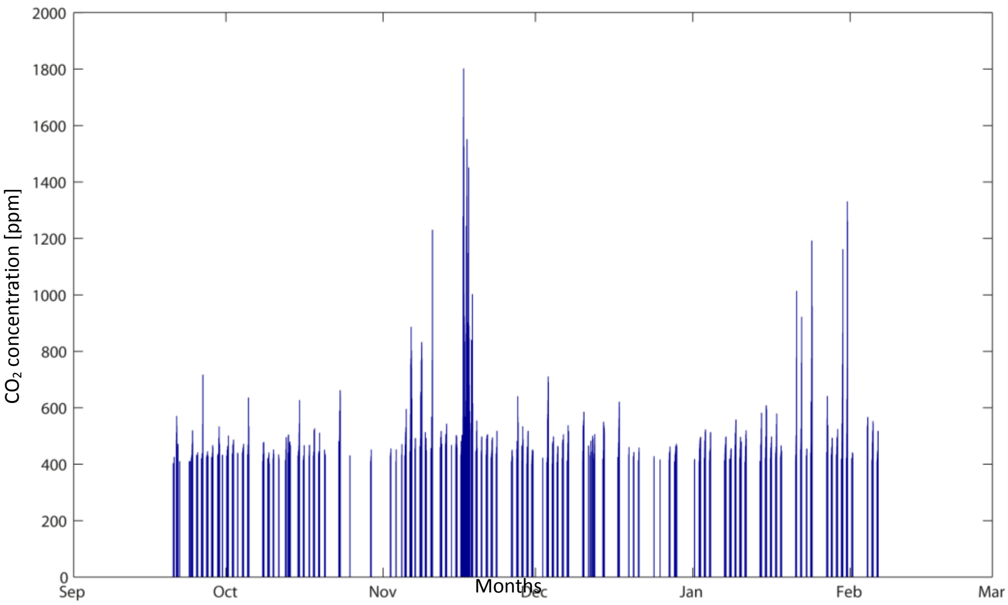


Figure 62. Occupancy per day [boolean] and related CO_2 concentration [ppm] of zone 2 from October 2012 to January 2013.

Psychrometric Charts

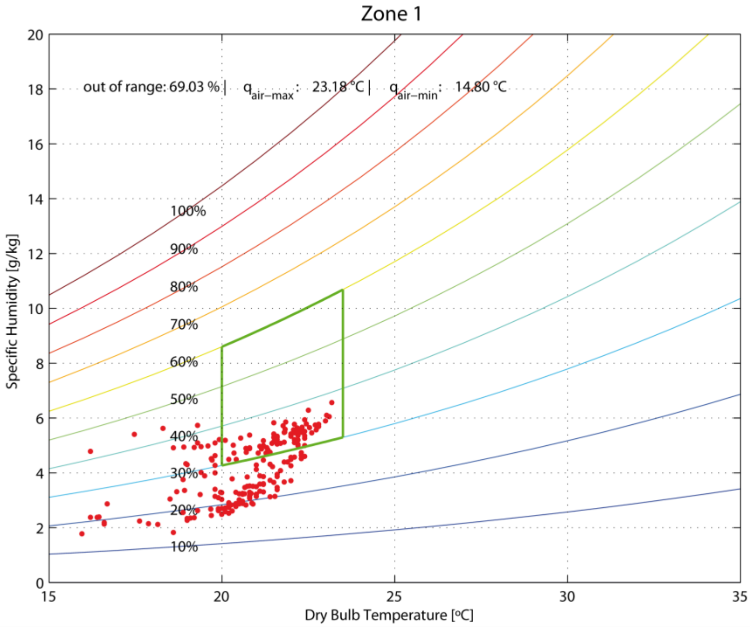


Figure 63. Psychrometric chart: thermal comfort zone, relative humidity, and internal temperature in the eastern seminar room (zone 1) for the measured period from 5th November 2012 to 31st January 2013 – measurements of occupied hours.

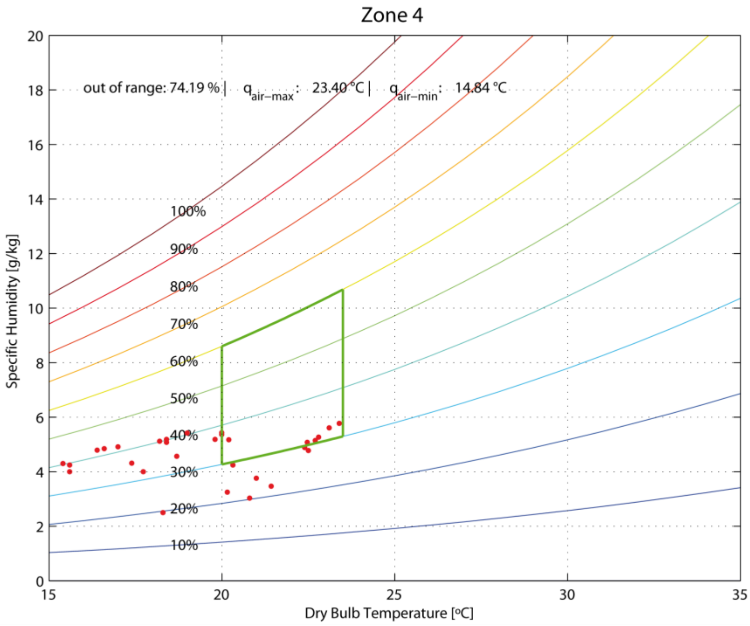


Figure 64. Psychrometric chart: thermal comfort zone, relative humidity, and internal temperature in the bedroom ground floor (zone 4) for the measured period from 5th November 2012 to 31st January 2013 – measurements of occupied hours.

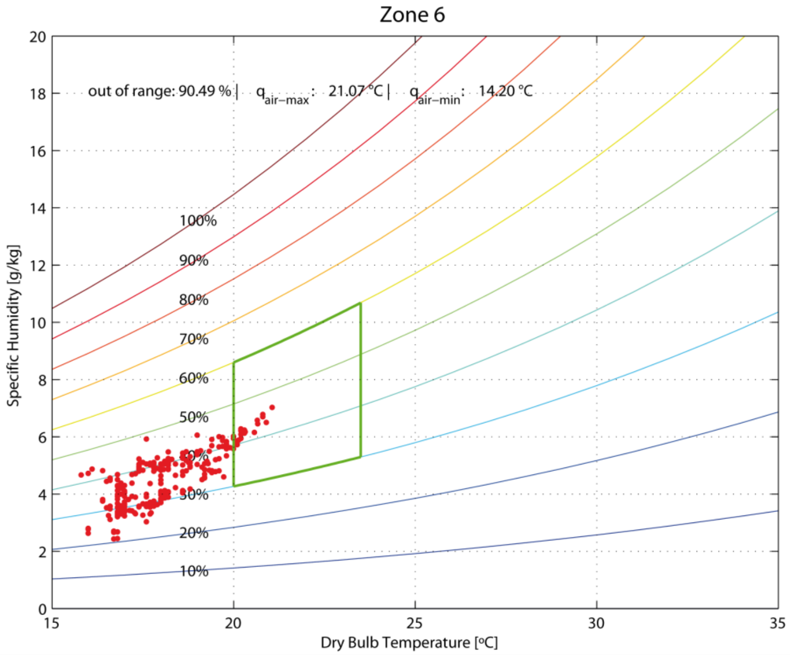


Figure 65. Psychrometric chart: thermal comfort zone, relative humidity, and internal temperature in the western seminar room (zone 6) for the measured period from 5th November 2012 to 31st January 2013 – measurements of occupied hours.

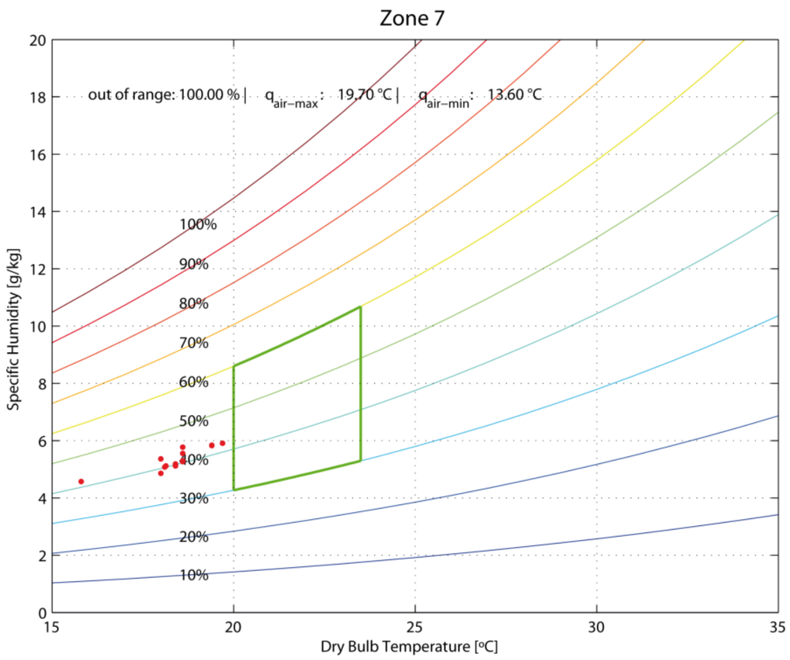


Figure 66. Psychrometric chart: thermal comfort zone, relative humidity, and internal temperature in the group bedroom 1st floor (zone 7) for the measured period from 5th November 2012 to 31st January 2013 – measurements of occupied hours.