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TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

MASTERARBEIT

INDOOR ENVIRONMENT, USER EVALUATION AND ENERGY USE IN A „PASSIVHAUS“ STUDENT DORMITORY

ausgeführt zum Zwecke der Erlangung des akademischen Grades einer Diplom-Ingenieurin

unter der Leitung von
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ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air- Conditioning Engineers
ISO7730	International Standards for Thermal Comfort-
OENORM	Standards published by the Austrian Standards Institute
OeAD	Österreichischer Austauschdienst

NOMENCLATURE

PMV	Predicted Mean Vote [-], used to evaluate thermal indoor comfort
PPD	Predicted Percentage Dissatisfied [%], used to predict discomfort for a large group of people
PHPP	Passivhaus Projektierungs Paket
PHI	Passivhaus Institut
WHO	World Health Organization
Q	Heat Flow [W]
U	Overall thermal transmittance
T_{air}	Air temperature
T_{op}	Operative Temperature in a specific point [°C]
T_{rm}	Mean radiant temperatures of the surfaces involved in thermal radiation for a specific point [°C]

1. ABSTRACT

During the past few years passive house technology has gained attention by the overall building energy efficiency and therefore it is becoming one global principle for sustainable building construction. Statistics show that in Austria alone, passive housing projects will increase from 12,000 to 130,000 by 2012. These numbers are influenced by recent Austrian federal and state government requirements for new subsidized housing projects where the use of the passive housing concept has to be implemented. The Passive House concept was developed in the early 90‘s however multi-story passive housing is relativly new in Austria and around the world. It is evident that sustainable building construction is one of the major factors in terms of energy conservation but its effectiveness is also dependent on the user interaction and behavior with a sustainable building. As the awareness about energy consumption continues, the interest in passive house of as method of construction has gained international interest. Energy costs will continue to rise and new methods of green building designs are becoming the requirement for future buildings.

In previous analysis of multi-story housing questions were raised when some passive houses showed possible issues concerning the air quality and its comfort level for the user. As a result the energy consumption could fluctuate as the user can actively affect the building`s performance. In green buildings the design of the complex technology works effectively to ensure the required performance but is yet missing the ability to control the ethnical engineering of the building to provide quality living standards. However, research shows that the user, the social and physical experience and the building performance are interconnected. The comfort of the user in a passive house with an automated control becomes a crucial element of the overall success of the concept. The user is not needed for the output of performance yet the system needs to be flexible enough to be able to interact with the user and allow for multi-user accessibility. Through a post occupancy evaluation in the Kandlgasse student housing it is possible to find comparable information about comfort, discomfort and reasons and therefore make comparable findings of energy consumption.

1.1 INTRODUCTION

The objective of this master thesis is to do an analysis of the energy consumption and the user satisfaction in a passive house student housing.

The analysis is based on a case study of the Kandlgasse student housing in Vienna whose construction standards are Austrian Passivhaus. This project is the second passive house student housing in Vienna and was finished in 2009. The student housing was used as an example of a multi-story passive house where the energy consumption and diverse users influence the interior comfort levels and the building's energy demand. A passive house must retain the energy while reducing the heat loss. As a result the building systems must provide a ventilation system that maintains comfort in the units at all times and throughout the year. Therefore the air condition is based on CO_2 levels as well as the relative humidity in the building. These are the parameters that define the users comfort level.

1.2 MOTIVATION

As the world is coming to a closer realization of the importance of reducing the use of non- renewable fossil fuel resources and the effects on climate change caused by their consumption; new technologies are developed. As a result, governments have taken a greater role supporting the new building standards and during the past years they are becoming implemented in the construction codes. Incentives given for sustainable construction are based on tax breaks, additional subsidies, project accessibility, energy cost reduction. However, as new technologies are developing and the existing methods of construction are evaluated it becomes important to compare the actual building performance against the calculated.

As mentioned before multi-story passive housing projects are considerably new. Currently, Austria is one of the largest builder of multi-story passive house projects because of a high demand. The intention of a passive house is the reduction of openings, thermal bridging and heat loss/ gains to control the energy balance. To achieve this it is also necessary to create an air tight building. The required technologies are more difficult and more important more costly with a large volume. This has to be considered based on the passive house standards.

The user has to adapt to sustainable designs and therefore it becomes more important to have an understanding of how to make these technologies more efficient and easier for the user and also for the building. A controlled environment like a passive house has to provide the same satisfaction levels for the users. A family residence built for one specific user can allow for a high interaction and control. In a multi-story student housing with rental apartments the same interaction may cause problems for the technical systems and lower the efficiency. Statistics show that buildings are some of the most apparent concerns in terms of energy consumption. Therefore it offers a high potential for energy reduction and passive house concepts offer that possibility. *“ Applied behavior analysis of energy use by consumer suggests that both antecedent and consequent conditions in most buildings often consume more energy use while discouraging conservation behavior (Geller et al 1982, p.58) investigating the Psychological effects of sustainable buildings on Human life.*

Questions:
Is the energy consumption in a multi-story building increased by its size and the diversity of the users?
What is the idea of student passive housing?
What are the expected vs. the current energy consumption values in passive housing?
How satisfied are the users living in a passive house building?
What is the relationship of passive house performance against the user interaction?

2. BACKGROUND

2.1. History

Historically after the Second World War the Economic and Energy Crises in the 70’s became a main factor for finding methods for reducing energy consumption. In the 90‘s Europe has become a leader in encouraging methods of low energy standards for buildings. In many cases the climate location required large energy usages to keep new homes or buildings heated. The passive house concept was developed with the help of Adamson and Gerd Hauser as well as the financial assistance of the State government of Hessen in Germany. The project started in 1991 when Wolfgang Feist and Bo Adamson designed the first Passive house in Darmstadt, Germany. They were members of the Institute of Housing and the Environment in Germany. The main principals of a passive house exited for a long time with methods of reducing thermal bridging in housing however one problem was the lack of materials developed for the construction of a passive house, for example air recovery systems.

2.2 What is Passive House?

The goal of passive house is the reduction of the energy usage in the dwelling to its minimum compared to traditional building codes. The design is overall successful in energy reduction and building internal comfort. In addition providing thermal comfort by post- heating or post- cooling of the building internal air climate. A passive house requires less than 10% of energy in comparison with 80% or more of the energy consumption by a standard building. In comparison with other green building standards who places little to no attention to the energy consumption passive house is a leader on the subject of energy conservation. It takes into account the primary energy demand of a building.
The building form, the ratio surface/volume, solar exposure, reduction of openings, reduction of thermal bridges, an airtight envelope, a ventilation system and high quality insulation are requirements for passive house. Of course, passive house designs that are based on high quality materials and additional technical requirements come with higher cost than standard building constructions. These costs are offset by minimal heating costs and by subsidies from state and federal governments.
“A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air.” (Feist 2006).
The standards are fundamentally defined in three parts:

1. Energy Limit (heating and cooling)
2. Quality requirement (thermal comfort)
3. The energy and quality requirements to be more cost efficient.

As a result the following became the “Passive house” standards:

4. The amount of energy consumption for heating, hot water and electricity must not be more than 120 kWh/m^2 per year.
5. Heat delivery looses must be within the limits +/- 1kwh/m^{2}a

In addition to the following criterias:

Compact form and good insulation:	All components of the exterior shell of the house are insulated to achieve a U-factor that does not exceed 0.15 W/(m²K) (0.026 Btu/h/ft²/°F).
Southern orientation and shade considerations:	Passive use of solar energy is a significant factor in passive house design.
Energy-efficient window glazing and frames:	Windows (glazing and frames, combined) should have U-factors not exceeding 0.80 W/(m²K) (0.14 Btu/h/ft²/°F), with solar heat-gain coefficients around 50%.
Building envelope air-tightness:	Air leakage through unsealed joints must be less than 0.6 times the house volume per hour.
Passive preheating of fresh air:	Fresh air may be brought into the house through underground ducts that exchange heat with the soil. This preheats fresh air to a temperature above 5°C (41°F), even on cold winter days.
Highly efficient heat recovery from exhaust air using an air-to-air heat exchanger:	Most of the perceptible heat in the exhaust air is transferred to the incoming fresh air (heat recovery rate over 80%).
Hot water supply using regenerative energy sources:	Solar collectors or heat pumps provide energy for hot water.
Energy-saving household appliances:	Low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc. are indispensable in a passive house.

Fig.1 Passive house Institute- (Feist, 2007)

2.3. Passive House and `Passiv Haus`

It is important to point out the difference between the name Passive House and `Passiv Haus`. The `Passiv Haus` are standards or set of rules that the Passive House Institute has implemented for building certification. On the other hand Passive House is the building method which are used for instance in a passive solar house. While other buildings can implement other passive design methods it does not mean that they follow the complete requirements of the `Passiv Haus` standards. Additionally other low energy consumption buildings standards such as low energy, zero carbon and others exist that implement parts of the same technology as `Passiv Haus`.
The Kandlgasse student housing project is certified with the `Passiv Haus` standard.

2.4. Subsidised Housing in Vienna

Vienna is considered one of the cities with the highest density of multi- story passive housing in the world. The first multi-story passive house was build at Molkensiegasse student housing in 2005. The Sustainable Urban Renewal- Best Practices UN- Habitat 1996 implemented in Vienna by the Wohnfond Wien promoting urban renewal improvement of the exiting neighborhoods as well as developer competition program guidelines for future building and urban projects. Both are required to follow the guidelines of the Passive House Standards. The cost of building construction are state supported and in some areas funded by the government to continue sustainable standards on a higher level. Some of the ecological aspects of new subsidised housing (City of Vienna, 1996).

- Low energy consumption Passive House
- District heating 30% from fossil energies
- Promoting alternative sources of energy
- Reduce power consumption by providing naturally lit stairs, low energy lamps, warm water supply for washing machine and dishwashers.
- Use of rainwater
- Use of HCFCs and PVC free materials
- Reduction of sealed surfaces
- Green roofs and facades
- Infrastructure in the immediate vicinity
- Environmental friendly building sites
- In the future: use of recyclable materials

Subsidized housing in Austria receives a loan by the state with an interest of 1% with a 30 years payment plan.

2.5. Energy Efficiency in Austria

As mentioned earlier Austria has become one of the leaders in finding methods of reducing energy consumption both at the construction level but also at the urban planning level. The rate of development has increased rapidly in Austria during the past few years.
The following figures 2 and 3 show the current Austrian statistics for future Passive House project.

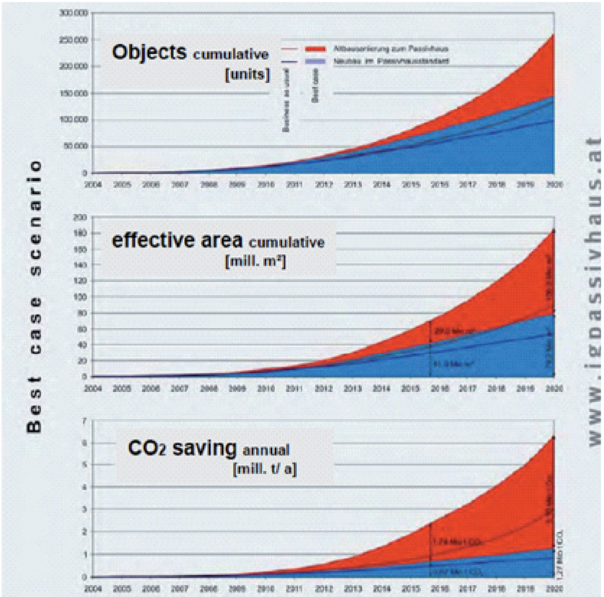


Fig.2 Energy efficiency of Passive House in Austria (IG PH, 2007)

Evaluation of the documented 463 Austrian passive house buildings:

Saved energy and emissions vs conventionally built structures	Status at 07/2006 **463** documented passive houses from Austria	Forecast 12/2006 **1660** built passive houses in Austria	**Forecast 2010** around **11,800** passive houses in Austria
New buildings	448 buildings	1,630 buildings	11,450 buildings
Refurbishment of existing buildings	15 buildings	30 buildings	350 buildings
Total number of buildings	**463 buildings**	**1,660 buildings**	**11,800 buildings**
New buildings floor space	291,696 m²	896,500 m²	6.300,000 m²
Refurbishment floor space	23,370 m²	49,800 m²	580,000 m²
Total floor space	**315,066 m²**	**946,300 m²**	**6,880.000 m²**
New buildings HER	16,043,280 kWh	49,308,000 kWh	346,000,000 kWh
Refurbishment HER	4,323,450 kWh	9,213,000 kWh	108,000,000 kWh
Total heating energy requirement (HER)/year	20,366,730 kWh	58,521,000 kWh	454,000,000 kWh
Heating energy requ./ year	**20,367 MWh**	**58,521 MWh**	**454,000 MWh**
Domestic fuel oil / year	2,037,000 l of oil	5,852,000 l of oil	45,400,000 l of oil
New buildings CO_2 savings	4,667 tons CO_2	14,300 t CO_2	100,800 t CO_2
Refurbishment CO_2 sav.	1,402 tons CO_2	3,000 t CO_2	35,000 t CO_2
CO_2 savings / year	**6,069 tons CO_2**	**17,300 t CO_2**	**135,800 t CO_2**

Fig.3 Evaluation of Passive House projects in Austria (IG PH, 2007)

2.6. Energy Efficiency in Passive House

The intention of an energy efficient dwelling is the provision of comfort while reducing the use of energy usage to achieve a stable comfort level at all times.

In a passive house one of the most important factors is the performance of the envelope and the management of the heat gains and loses of the building.

The sum of the heat loses = the sum of the heat gains. (PHI, 2007)

A passive house uses less than 1.5 liters of heating oil and therefore reduces the amount of CO_2 gasses being emitted to the air. Compared with standard constructions the heating demand is reduced by 90%.

Heat gains

Solar heat (passive solar energy)

Internal heat- heat radiated by humans or living animals

Heat transfer thru the envelop of the building inside

Heat produced by appliances or other equipment

Heat loses

Ventilation loses

Loses to outside air

Loses that could occur at windows, ground floor, roof, thermal bridging

2.7. Passive House Technology- Building Systems

In a passive house the energy efficiency of the building is dependent on the materials used on the building as well as the methodology of construction.
for example:
Insulation, ventilation system, thermal heat loss coefficient (U-values), Airtightness, Windows and frames U-values.

2.7.1 Insulation

Insulation value in the building's shell or façade is equal to 0.1 W/m²K depending on the building location and climate. At the roof the heat loss coefficients is around 0.2 to 0.15 W/m²K The insulation type is depended on its thermal conductivity while some materials might have different U values (W/m²K. When in the construction of the building envelope there are other materials that contribute to reduce or increase heat conductivity.

Table 1 provides the thermal conductivity values of the materials used in a passive house project.

Tab.1. Building Materials and thermal conductivity

Material	Thermal Conductivity W/mK	Thickness U= 0.13 W/(m²K)
Concrete	2.10	15.8
Hallow brick	0.40	3.01
Wood	0.13	0.98
Typical Insulation	0.04	0.3
Straw	0.055	0.410
Vacuum Insulation	0.002	0.015

2.7.2. Thermal Bridging

Thermal bridging is produced by high conductivity materials with the result of high heat losses. In building construction thermal bridging occur in locations where two or more materials are adjacent to each other, for instance at joined connections, i.e. balconies, floor/wall connections and walls in basements or underground parking.

The results of thermal bridging are:

Heat loss or heat gains.

High humidity by the high differentiation of temperature between indoor or outdoor areas

Thermal bridging is avoided by the use of materials, mainly insulation and airtight construction methods with foils and sealants. Another indicator of possible heat losses is when the thermal coefficient is less than 0.01 W/mK. *Based on passivhaus standards.*

2.7.3 Airtightness

The efficiency of a passive house is also based to contain the airflow coming in and out of the dwelling. As the warm air inside a building contains the most energy it is crucial to completely seal all surfaces. Especially all openings are to be sealed with special tapes. Pressure testing measurements can be done to have the correct assessments for permeability. The linkage rate should be $0.6h^{-1}$ or less.

2.7.4. Ventilation

In a passive house the ventilation system is a key element to maintain indoor air quality. The ventilation system will pull air out of the kitchen; bathroom and then supply it to the living room while the fresh air will be supplied to the sleeping rooms. The adequate exchange rate in a passive house while energy usage and the indoor comfort levels can affect the users comfort levels . “The air change per hour in a non- conditioned space is 0.33/h with 3 hours 5 minutes with the windows open” (PHI, 2007).
The recommended exchange rate per hour for a room is 3-4 n (1/hr).

Fresh Air Supply for a Room:

$$Q=nV$$

q= fresh air supply (ft^3/h, m^3/h)

n= air change rate (1/n)

V= volume of room (ft^3, m^3)

The ventilation systems in a passive house could varies according to the area and the size of the building. The following are common ventilation systems used in passive houses:

Centralized:	A central plant that supplies and exchanges air for the whole building and is commonly used in multi-story projects.
Decentralized:	Each room may have their own ventilation.
Combined:	Both systems are used.

2.7.5. Window Types

Windows are the represented sources of possible heat losses location and represented it location for heat gain from external light and solar heat coming into the building. Based on the Passive house requirements the U-Value has to be less than 0.85 W/m^2K. The best performing windows are triple glaszed windows, where there is very little air gap and the heat loss coefficient is more than half. However, it is important to consider the climatic location of the building to reach equivalent thermal comfort in the building.

“In (EU standards EN 10077) a temperature of 17° Celsius around a window is still thermally comfortable which is achievable with a triple glass windows”.

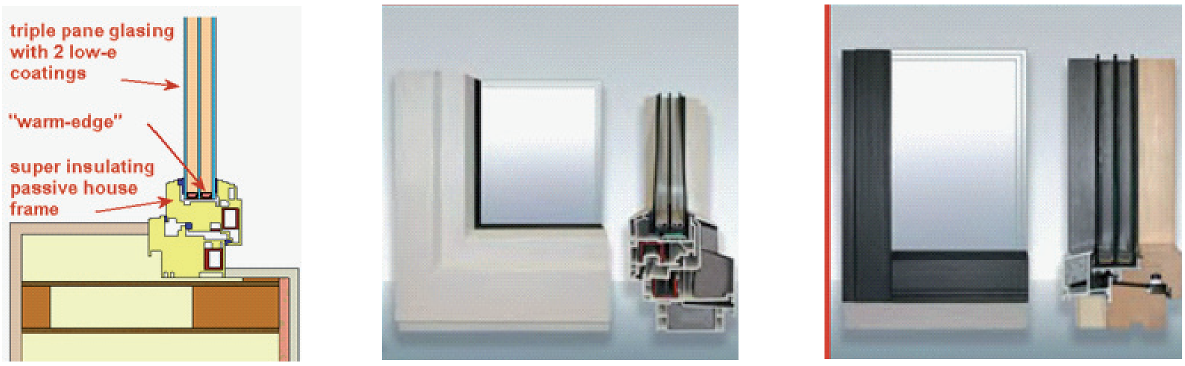


Fig.4 Window types suitable for passive house- providing insulation at frame (PHI, 2007)

2.8. Indoor Air Quality - Thermal Comfort

In a passive house the interior temperature of a room should be 20°-24° Celsius.
(PHPP 2007,p. 35)

According to OENORM EN 7730, 2006 the body comfort temperature is between 34 Celsius. When talking about thermal comfort we must recognize that when we are talking about the interaction between the building and the human body . In most societies we live in an artificial environment supported by some type of mechanical system. In a passive house building it is even more evident that the thermal comfort is dependent on the access of natural air and desired ventilation conditions of the building working for the user. ASHRAE standards mention that Thermal Comfort for a person is the condition where expresses satisfaction with the thermal environment (Fanger 1970).
The Fanger model for thermal comfort is based on six basic elements: air temperature, humidity, mean radiant temperature, relative air velocity, activity level and the insulation value of clothing.

Equation : (Fanger, 1970)

$$H - (Ed - Esw) - (Ere - L) = K = R + C$$

H= The internal heat production of the human body

Ed= The heat loss by water vapor diffusion through the skin

Esw= The heat loss by evaporation of the sweat from the surface of the skin.

Ere= The latent respiration heat loss

L= The dry respiration heat loss

K= The heat transfer from the skin to the outer surface of the clothed body

R= The heat loss by radiation from the outer surface of the clothed body

C= The heat loss by convection from the outer surface of the clothed body

In the conditions of passive housing when the intent is to reduce the energy consumption and successfully build a green building it is important to view the behavior and psychology of the user needs and activities in the building . A passive house project will need to perform but also provide the basic needs of a quality living environment.

THERMAL COMFORT CONCEPT

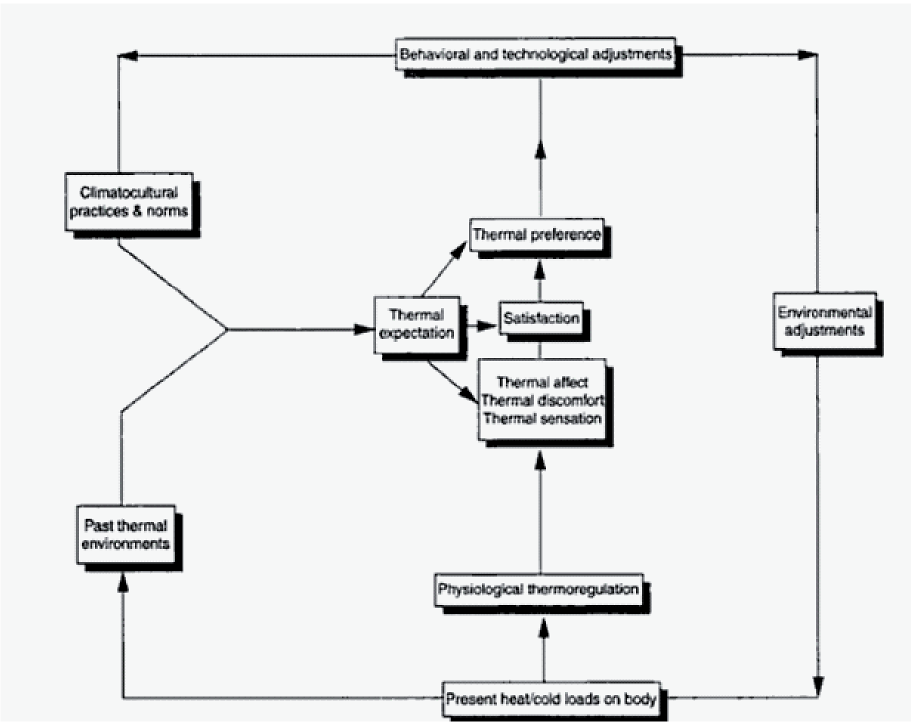


Fig.5 Adaptive model of thermal comfort 9 from (Szokolay, 2004)

2.8.1. Predictive Mean Vote (PMV) Sensation

The method in which thermal comfort can be evaluated by scale and on the type of activity or clothing material the person is. The equation is to provide the combination of variables to achieve thermal comfort. The scale is ranging from -3 to 3 (Fanger 1970).

$$PMV= (0.303 e^{-0.036M} + 0.028) L$$

M= metabolic rate
L= thermal load- defined as the internal heat production.
based on ISO 7730 PMV
Energy conversion M = 46-232 W/m2 (met 0.8 to 4)
Thermal resistance of clothing Icl = 0 to 0.310 m2 K / W (0 to 2 clo)
Relative air speed var = 0 and 1 m / s
Air temperature ta = 10 to 30 Â ° C
Mean radiant temperature tr = 10 to 40 A ° C
Humidity (water vapor) pa = 0 â € “2.700 Pa

2.8.2 Predicted Percentage of Dissatisfied PPD – Percentage of the thermal environment

In relation to the Predicted mean vote the level of satisfaction of a room should be in reference to the whole floor area and the temperature readings that should reach a minimum percentage of 5%. The PPD measures the thermal comfort of a whole group of people. The PPD determines the percentage of thermally dissatisfied people based on the terms cold, warm, slightly warm, neutral, -1 slightly cold -2 cold and -3 cold.

$$PPD=(100-95e^{-(0.03353\ PMV\ +}\ 0.2179\ PMV^2\ )L$$

When we are talking about building performance and the occupant there are three categories that classifies thermal comfort (Spengler, 2000).

1. Behavioral Adaptation- based on the clothing and body movement to reach satisfaction levels in the body and the surrounding environment.

2. Physiological Adaptation- Adjustment of internal environment for a long-term period of time. The physiological adaptations of a place environment to sustain the thermal conditions of the place.
3. Psychological adaptation- the experience that an individual might have in a place and his/her understanding of the thermal conditions and possible expectations of the building performance of the place, when defining preconceived notions of the place.

2.8.3. Relative Humidity

When talking about thermal comfort relative humidity is also a factor in the user's satisfaction of a space. The relative humidity of a standard space should be 35% to 60% equal to 20° Celsius for a comfortable environment. The relative humidity is depending on the outside air coming in the building and its distribution of fresh air (PHI 2007).

$$\text{Relative humidity} = \frac{\text{Actual Vapor density} \times 100\%}{\text{Saturation Vapor density}}$$

The need to maintain a minimum relative humidity of 35% is necessary as the human body is very sensitive to humidity. When the relative humidity is higher than 60% mold can start to appear which causes serious health issues for the user.

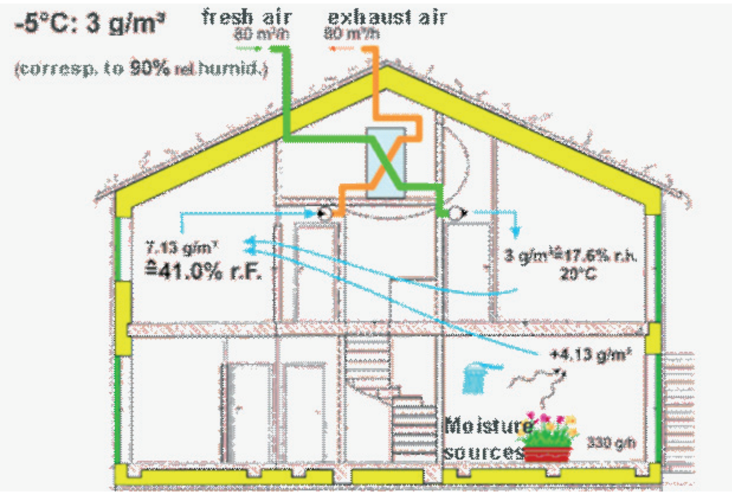


Fig.6 Scheme of a Passive house ventilation system (Feist,2007).

Table 2 shows the relative temperature is a combination of air temperature and radiant temperature. For relatively uniform environments, radiant temperature is equal to air temperature.
Table Based on ASHRAE 2004

Tab.2 Acceptable Operating Temperatures as Specified by ASHRAE 55

	Conditions	**Acceptable Operative Temp**
Summer	Relative Humidity 30%	24.5-28 C (76-82 F)
	Relative Humidity 60%	23-25.5 C (74-78 F)
Winter	Relative Humidity 30%	20.5-25.5 C (69-78)
	Relative Humidity 60%	20-24 C (68-75)

2.9. Indoor CO_2 Carbon Dioxide Levels

The average person spends 80 to 90 percent of their time indoors. Therefore the air quality of the room can affect the performance and/or the health of people in their daily activities. In addition indoor environments are also subject to the exposure of organic compounds in the air. As a result the lack of good air circulation could have major effects on their health. The World Health Organization WHO recommends that the levels of VOCs be reduced to a limit of 0.5 milligrams per cubic meter. *“The outdoor air CO_2 concentration of 400 ppm in a urban area in a busy road is about 500 ppm”* (WHO, 1997).
Based on the ONORM EN 13779 CO_2 concentration standards with a 800 ppm above CO_2 outdoor air, the maximum indoor concentration in room should not be more than 1,200 ppm.

Airflow equation from OENORM EN 13779

$$Q_vZUL= q_{m.E} / C_{RAL} – C_{zul} \times 10^3$$

Q_{xzul} = Air flow rate ($m^{3.} H^{-1}$)
$q_{m.E}$ = Volume of Emission in space (l/h)
C_{RAL} = Allowable concentration in Area (ppm)
C_{zul} = Concentration in the air (ppm)
In a passive house, $C0_2$ is considered not only for the interior environment but also in the amount of the CO_2 emissions produced by energy consumption using alternative methods of renewable energy.

Table 3. Indoor air quality set for a building but yet dependet on the user activity or indivual needs.

Tab.3 Evaluation of indoor air quality (OENORM EN 13779)

Category	Increase in CO_2 Concentration over the outdoor air quality ppm		Description
	Typical Range	Default	
IDA 1	400	350	Specific indoor air quality
IDA 2	400-600	350	High indoor air quality
IDA 3	600-1,000	800	Mean indoor air quality
IDA 4	> 1,000	1,200	Low indoor air quality

2.10. Photovoltaic Systems

The use of photovoltaic systems has steadily increased in the Austrian market as the demand for solar energy is growing for financial and ethical reasons. Subsidies and state funds support the growth. In addition the use of photovoltaic systems provides the opportunity to reduce the demand of electricity and therefore the reduction of CO_2 emissions.

2.11. Green Roofs

Austria has become a leading actor in the implementation of green roof designs. The implementation of the OENORM L 1131 standards since 2010 in building projects allowed for the standardization of roof garden building methods. Some of the benefits of the green roof are:

- High water retention
- Reduces the heat gains during the hot season
- Absorbs greenhouse gases
- Construction materials can be recycled materials
- Aesthetically more attractive especially in cities where green areas are often scattered and yet they can improve the urban fabric Water reduction- the runoff water management
- Thermal benefits in the case of passive housing is a benefit since green roofs can also become a barrier of heat gains during hot weather by a given U-value.

2.12. Lighting

The indoor comfort is also influenced by the amount of natural light that affects the behavior of the user and the physiological comfort of a place. In addition, quality of lighting either natural or artificial is also important for the reduction of energy usage in a building. Based on ASHRAE 55-92 and ISO 7730 the outdoor luminance level is approximately 1000 lux on a bright day. Indoors the luminance levels depend on the type of activities in the room. In the case of the student housing, the activities are a mix of work, task performance and home general activities with a range of 150 to 250 lux/m^2. In a passive house it is important to consider the interior heat gains of the building to avoid the additional use of the ventilation supply. The passive housing principals consider the building orientation, window locations as well as possible heat gains from electronic equipment and artificial lighting.

2.13. Post Occupancy Evaluation

A post occupancy evaluation involves the user and their perspective of the current living quality and their experience in this building type, in this case the student housing. This evaluation's intent is to be able to understand and assess if the needs of the user are being met or if they are lacking quality. When talking about a post occupancy evaluation the people interested on the findings are designers, developers, managers or owners that provide feedback prior or after the building construction. The benefits of a post occupancy evaluation are: Improvement for future buildings, cost estimates, building renovations, improvement of living standards or accountability. (Post Occupancy Evaluation)

2.14. User Evaluations- questionnaire

The questionnaire is divided in three user types: The building maintenance personal, building housekeepers who are cleaning every unit and who are aware of the building condition and the user who is the actual resident of the unit. I provided a series of questions to each user that relate to comfort, building condition, health, passivhaus concept, aesthetics, operational cost, life cycle cost, site and the surroundings. The questionnaire was submitted and reviewed with previous questionnaires done in the past with students.

3. METHODOLOGY

3.1 Building Description

Student Housing Kandlgasse 30

The Kandlgasse student housing is the second passive house student housing in Vienna Austria. Owned by the OeAD Housing who provides housing for students, visiting Erasmus students or visiting professors.

3.1.1. Student Housing Building

The student housing project is located in the center of Vienna in the seventh district. It is in walking distance to the public transportation U6 Burgasse as well as the tram lines 5 and 49 along Kaiserstrasse and Westbahnstrasse. This is the first infill Passive house student housing project in Vienna. The building consist of 105 single rooms with four different typologies ranging from one to four bedrooms units. The building provides a community area at the main entrance level as well as a laundry room and game room in the basement.

Fig.7 Aerial map of Student housing Kandlgasse 30 (Google ,2011)

Fig.8 Main entrance

Fig.9 Courtyard

3.1.2. Building Structure

Architects: Atelier 4 Architects

Client: OeAD-WohnraumverwaltungsGmbH

Developer: OSW Oesterreichisches Siedlungswerk- Gemeinnuetzige Wohnungsaktiengesellschaft

Consultant: Schöberl & Pöll OEG

Building Cost: 5.3 Mio € net (ÖSW)

Funding from the City of Vienna: 2.11 Mio € (ÖSW)

The Kandlgasse Student Housing project was built in 2009. The seven-story building with a net usable floor area of 3.104m^2 is composed of two seperate buildings. The main building along Kandlgasse is facing south and the wing courtyard building connected by an open deck faces east. The main building is accessible through the main central stairs and an accessible elevator. It has a light shaft that allows for natural lighting into the main corridor. In addition, the main building is not directly connected to the other building allowing the access of natural light to the main circulation area. The wing building is accessible through a main connection door that exits to the main deck to access the dormitory units on all all levels. At the basement level of the main building is a laundry room for all residents as well as private courtyard for residents. Located at the North-East corner is an underground public parking required by city officials.See Table 2 for the building area.

In table 4 building current floor area for building A and B

Tab.4 Building Gross Floor area (Mandfred, 2008)

Kandlgasse	**Area (m²)**
Net usable area	3104 m^2
Total Gross floor Area	2738,72 m^2

3.1.3. Building Site

Building B is considered while the structure is isolated from the building A . When taking into consideration the conditions of the site which is an urban infill, the building is fitted in between two residential buildings at the west and south side of the building.

In the project are mostly single rooms with kitchenette, a bathroom and toilet as well as residential

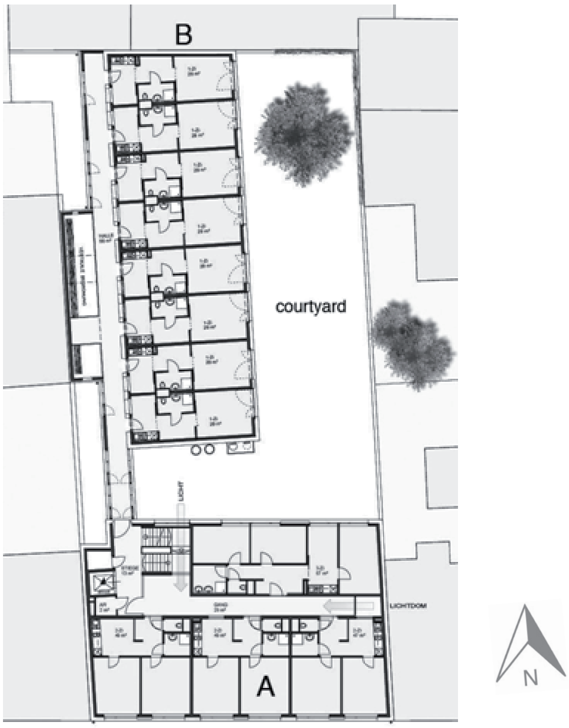


Fig.10 Floor Plan - Atelier 4 architects

Units types per building shown in table 5

Tab.5 Student Housing Unit Types

Building	**Unit**	**Area (m²)**	**Volume (m³)**
Building B	1 bedroom	29	251
Building A	2 bedroom	49	251
Building A	3 bedroom	67	251
Building A	4 bedroom	101	280

units where the resident has a private room and supplementary rooms such as bathroom, toilet and kitchen which are shared with others residents in the unit. In total there are 105 rooms in 73 residential units. 42 are located in the courtyard wing (B) section 42 and 31 residential units in the main building (A).

The only connection to the building is a main corridor that is structurally isolated to avoid thermal bridging in both buildings.

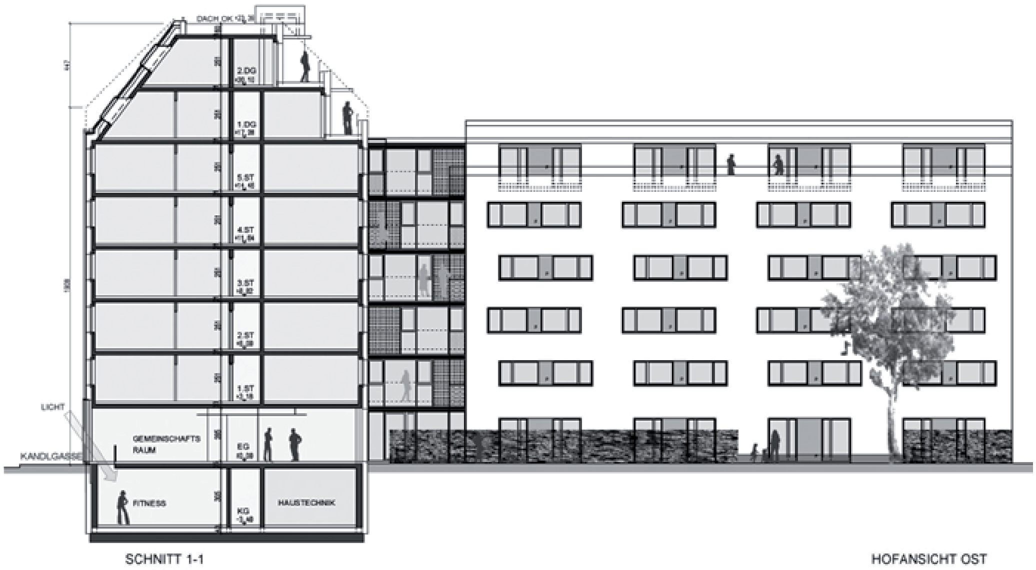


Fig.11 Section main building (A) and elevation courtyard wing (B) - Atelier 4 architects

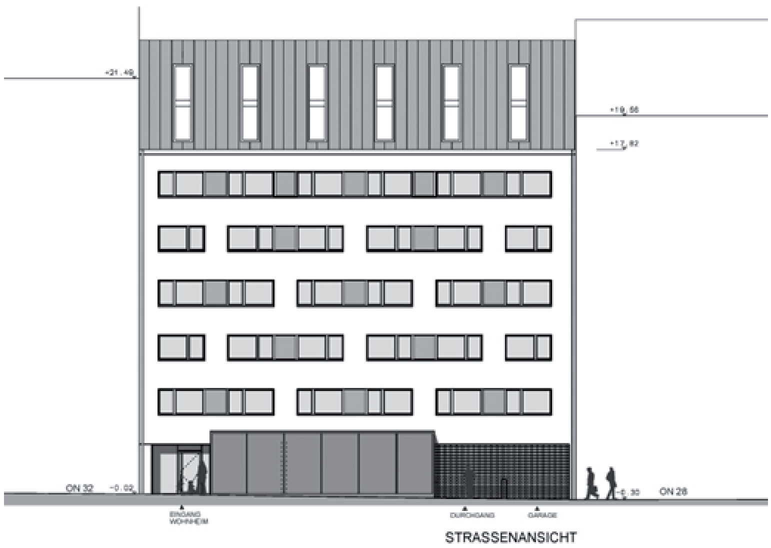
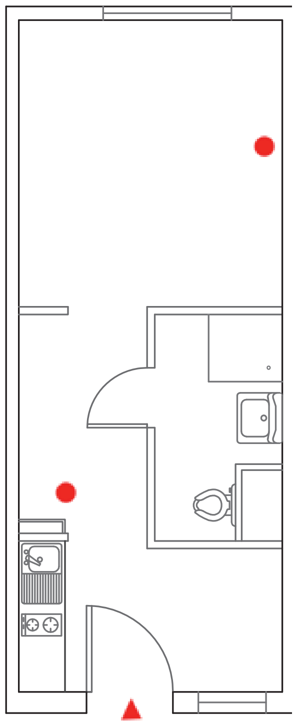
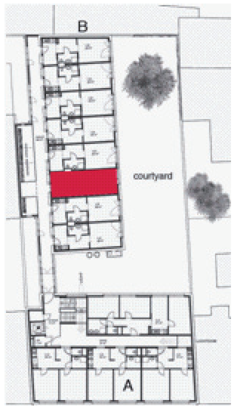


Fig.12 Elevation main building (A) - Atelier 4 architects

One Bedroom (Studio) : T1





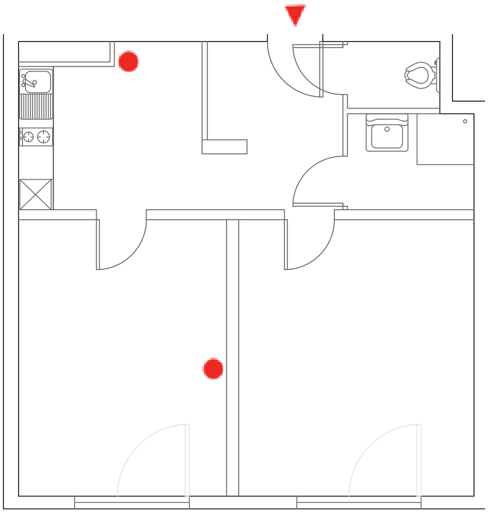
co^2 monitor
HOBO monitor
entrance

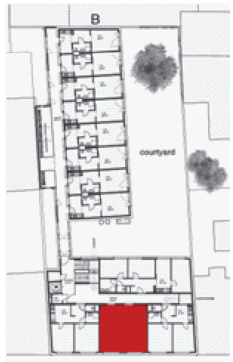
Fig.13 Plan - Building B Unit

The one-bedroom units that are located in building B are 29.40 m^2. The units are designed for only one person. It provides a small kitchenette and a bathroom with a toilet and a shower. The sleeping and living area is combined with enough space for a desk and a twin size bed. A large window faces east, as well as a small window at the main entrance of the unit that faces west to the open hallway. The measuring devices were placed in most of these unit types at the dresser area and the top shelf of the sleeping and living space.

Fig.14 Sleeping/ living area

Two Bedroom Unit: T2





co^2 monitor
HOBO monitor
entrance

Fig.15 Plan - Building A Unit

The two-bedroom unit are 49.02m^2 and faces south, with windows for both bedroom units, an open kitchen and dining or living space and one shared bathroom. All units provide a shelf or rack space at the entrance of the unit. The monitors were placed in the kitchen/ living room area and in one of the units. However, there are occasions where the monitor was placed at the hall adjacent to the bathroom wall.

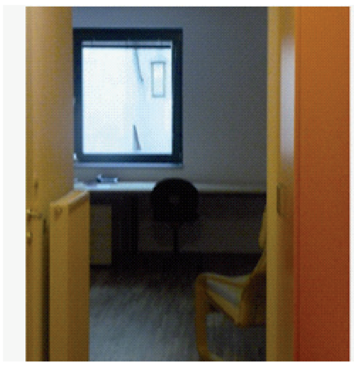
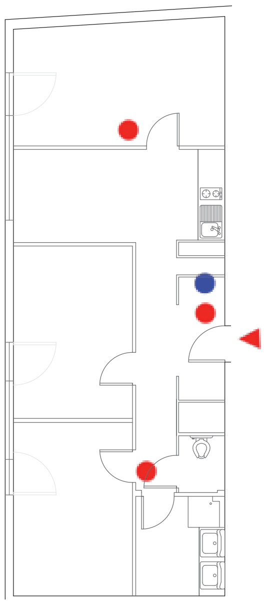
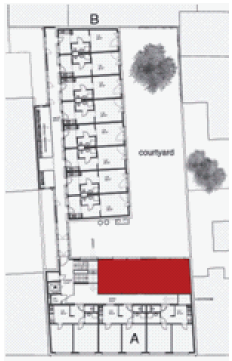


Fig.16 Bedroom

Fig.17 Kitchen area

Three Bedroom Unit: T3





● co^2 monitor
● HOBO monitor
▲ entrance

Fig.18 Plan - Building A Unit

The three-bedroom unit is 67m^2 and faces north. the bedrooms are oriented to the courtyard while all the other services are facing the internal hallway walls.

Fig.19 Kichen/ Living area

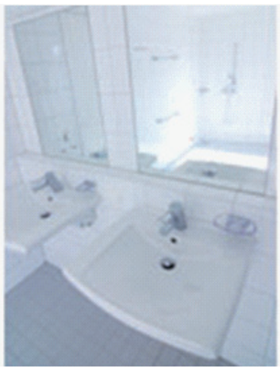
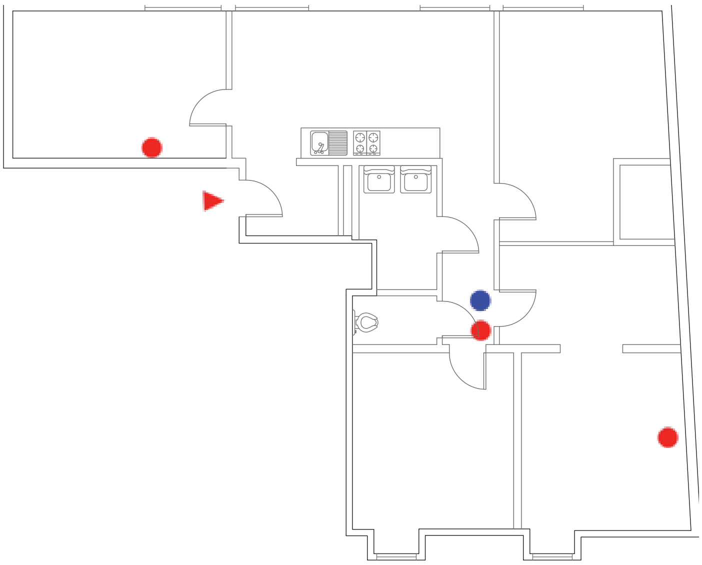
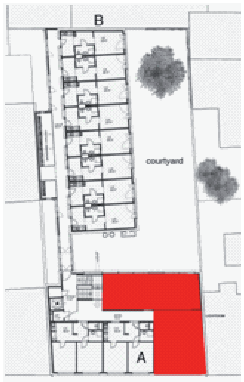


Fig.20 Bathroom

Four Bedroom Unit: T4





co^2 monitor
HOBO monitor
entrance

Fig.21 Plan - Building A Unit

The four bedroom units are 101m^2. They are located on the 6th and 7th floor of the main building. The pitched roof provides a large amount of natural lighting to the north and the south facing rooms.

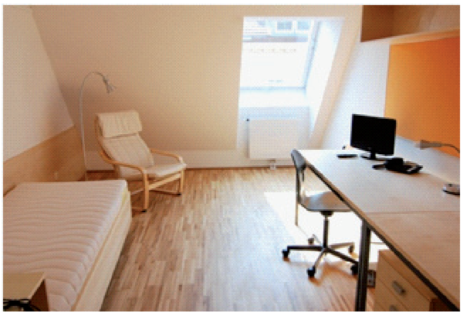


Fig.22 Bedroom

Fig.23 Kitchen/ Living area

3.1.4. Building Living Standards

The building units have a similar floor plan layout; the main sleeping and living areas are facing the exterior façade for natural lighting while the service areas are facing the adjacent corridors. The units are equipped with light-coloured wood flooring. The kitchens provides a 2 or 4 electrical stove, a microwave, a refrigerator and an air filter for air flow when cooking. The filter is not connected to the outside but blows the filtered air back into the kitchen area. All appliances are energy efficient based on the reviews done by Schöberl & Pöll. The washing machine room is located in the basement and is equipped with three washing machines and tumble dryers. Based on the EU appliances grading for lower energy consumption they should be graded A to G that indicates best energy performance.

FIg.24 Kitchen block

3.1.5. Building Materials

In the construction of a multi-story passive housing needs to equally perform as single story passive housing. However PHPP calculations are necessary to consider the building dimensions, material exterior exposures, locations for possible thermal bridging, window types, heated or unheated spaces specially in a multi-story building.

The building has an insulation of 30 cm of EPS- F at the front façade of building A to prevent heat loss, in addition to an 18 cm reinforced concrete wall. The courtyard wing façade is 38 cm of EPS- F with 18 cm reinforced concrete wall and has an heat transfer coefficient of U= 0.082 W/m^{2}K.

The interior walls are made of a drywall system planked with gypsum boards in between units. In locations with a possible temperature difference the walls are 15 cm thick with a heat transfer coefficient of U= 0.401 W/m^{2}K .

Table 6 provides building construction materials for exterior wall thickeness in a passive house. information p (DI Kath, 2010)

Tab.6 Exterior wall thickness

	Size	Building Element	U- Value (W.(m^2.(m^2.K)-1)
Courtyard wing	38.0 cm	Exterior Wall	0.082
Front Facade	30.0 cm	Exterior Wall	0.104
Main Façade	22.0 cm	Exterior Wall	0.140
Courtyard wing	30.0 cm	Exterior Wall	0.116
Non- heated Space	30.0 cm	Exterior Wall	0.412

3.1.5.1. Roof Construction

Outdoor ceiling in the outer cover in part is composed of soil, screed 18.0 cms concrete as well vacuum insulation, fire protection and bonded layer. Heat transfer coefficient U= 0.140 W/m^2. The terrace heated 4.0cm concrete slab and heating transfer coefficient U= 0.115 W/m^2K. Ceilings between apartments separating floors are 18.0 cm with a heating coefficient U= 0.661 W/m^2K.

Non- heated areas

Garbage room with cold bridge insulation form the outside wall as well as thermal bridge insulation with a heat coefficient U= 0.162 W/m^2K

Waste room with a heat coefficient U= 0.524 W/m^2K

Porch Floor– Concrete slab, outside the thermal envelope the wall is designed outside the internal wall envelop. The heat transfer coefficient u= 0.523 W/m^2K.

3.1.5.1.1 Green Roof Construction

The courtyard building has a green roof coverage of 3,458 m^2. The extensive green roof is mostly covered with grasses and herbs. Some of the benefits of the green roof are:

- High water retention
- Reduces the heat gains during summer
- Absorbent of greenhouse gases
- The materials of construction can be recycled materials
- Aesthetically more attractive- Green

Green Roof about 25 cm with a U=0,289 W/m^2K

Green Roof over garage this is considered an unheated space at ambient air. The use of cold bridge insulation and thermal insulation is used from the outside wall. A heat coefficient of U= 0.289 W/m^2K.

Pitched roof located on the upper two floors of the main building. Constructed of wooden formwork with a thermal transfer coefficient U= 0.113W/m^2K.

3.1.5.2. Floor Construction

Floor at basement- unheated space with cold bridge insulation. The heat transfer coefficient U= 0.217 W/m^2K.
Ground Floor- non-heated space with a heat transfer coefficient U= 0,330 W/m^2 K.
Between Floors- heated room with a heat transfer coefficient U= 0.661 W/m^2 K.

3.1.5.3. Windows and Doors

The windows are triple-glazed with a wood framing and an aluminum protection. They are equipped with an internal louver shade.
Heat transfer coefficient of (frame+glass)= U≤ 0.80 W/m^2K and total transmission of the windows g ≤ 0.48. Ug= 0,70 W/m^2K.
The windows at the skylight in the upper floor have a heat transfer coefficient (frame+glass) U≤ 1.50 W/m^2K and the total energy transmission of the glazing is g ≤ 0.56. Based on the OENORM EN 12665- 2009- Light Techniques in Austria is required to provide a 10% of window area based on the overall floor and the depth of the room.

3.1.6. Day lighting

The kandlgasse student housing implemented the use of natural lighting shafts for the main building. The separation of the two buildings from each other allows additional windows at the main circulation stairs. In addition, an open sectional shaft at the main office of the building provides natural light to the laundry facilities located in the basement that otherwise would have required artificial light to reach positive luminance levels.

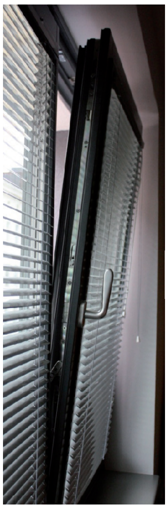


Fig.25 window *Fig.26 window bedroom*

3.1.7. Building Current Energy Usage

In the kandlgasse project the use of 30-38 cm of insulation provides the base for 90% of the reduction of energy usage in the building. It is built airtight as well as insulated in all possible locations within the thermal envelope. In locations where a heat lose can occur outside of the building's thermal evelope a 4 cm insulation was placed on the ceiling of the building, in this case the basement at the water heating room.

Technical System – Energy conservation.

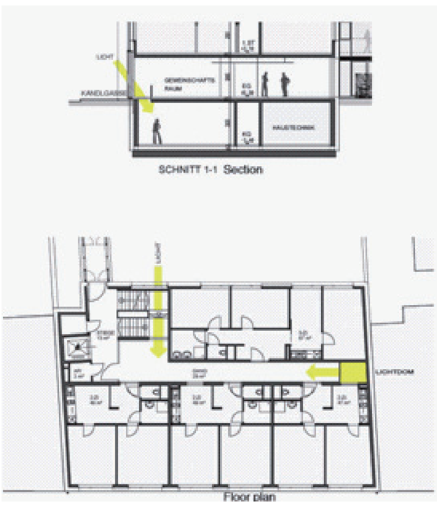


Fig.27 access of natural light *Fig.28 Light shaft* actual heating demand (HWB) = 15kWh/m^2

The unit's radiators are located in the kitchen/ living area and in the sleeping room above the door. FERNWAERME city of Vienna provide the warm water for the radiators and the building. The room temperature could be set between 17°C and 25°C in the unit's thermostat.

While the residents might still find a need to ventilate the room with fresh outside air the thermostat system when reaching 16°C will deactivate when the window is open and it will not continue until the windows are closed again. However, it is important to know that if the temperature is too low the

Fig.29 4cm insulation at hot water room

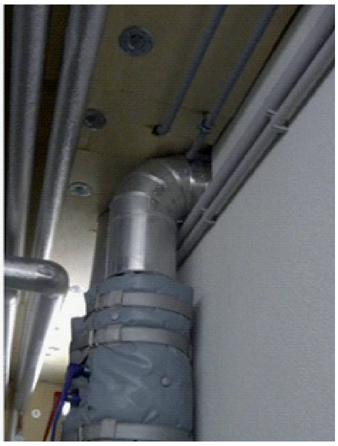


Fig.30 4cm insulation at hot water room

heating system will need to reach the normal temperature of the room. Radiator heat, unit electrical appliances can also emition of heat human body heat and solar heat are considered heat gains in the building. In the student manual there is a reminder for students to not close the blinds in winter to allow thermal solar gains, while in the summer it is important to use them to reduce the amount of heat coming into the building that will internally will heat the place at higher levels that the norm .

3.1.7.1. Heating and Warm Water

Heating system for all units and distribution method shown in table 7.

Tab.7 Current heating building demand - PHPP

Heating demand by Specifications (HWB)	**15kWh/ m² PHPP/ Heat load: 10.00 W/m²**
Heating	Radiator
Heating distribution	Water system
Unit heating	Radiator in the room above door and space heater in kitchen and living room/kitchen area

Fig.31 thermostat

Fig.32 radiator in kitchen/ living area

the district heating provided by FERNWAERME supplies district heating to the ratiators system for each unit. Is unit is equipped with a radiator per room to provide the option to residents to use them when the feel the temperature is too low.

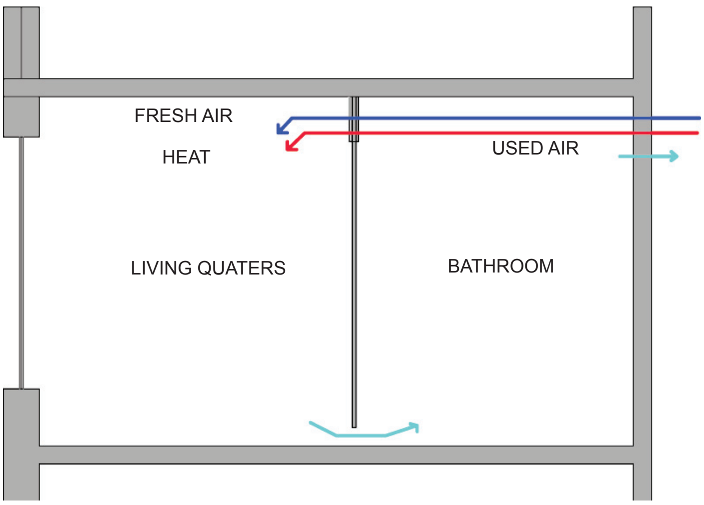


Fig.33. air exchange diagram

Fig.34 radiator, ventilation outlet and thermostat in bedroom

3.1.8. Photovoltaic system

The Kandlgasse project is the first student housing project that implemented a photovoltaic system for energy generation. The intent of using photovoltaics in the building was not only to reduce the amount of energy used by regular energy provider but also to be able to produce green energy for the building to reduce the CO_2 building emissions. The photovoltaic system in the kandlgasse project is supported by Oekostrom, Austria who’s emphasis is the production of cleaner energy to reduce $C0_2$ emissions by using neutral solar products.

The photovoltaic system is located in the south facing roof on the main building “A”, the flat roof as well as the front façade of the building on the upper floors. The overall cost of the pv system came up to 157.406 € net including a financial support of 53.784 € from the city of vienna.

Fig.35 4 kWp flat roof at 30 degrees

Fig.36 1.2 kWp front façade at 90 degrees

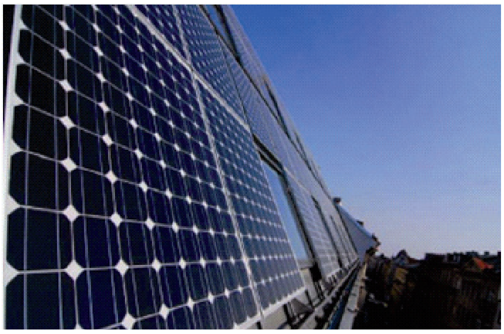


Fig.37 14.7 kWp pitched roof at 58 degrees

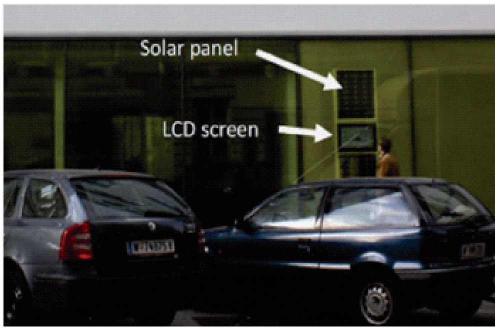


Fig.38 Informational LCD screen at main entrance for daily kWp readings.

Tab.8 Photovoltaic system

Location	Modules	Area	Performance
Pitched roof	64	64 m^2	230 Wp/modul
Flat roof	18	109m^2	220 Wp/modul
Front facade	5	10.50m^2	247 Wp/modul
Total	86	150m^2	697 Wp/modul
Savings 1800Kg CO_2			

3.1.9. Ventilation System

The building has a heat recovery ventilation or centralized ventilation system. The central system brings fresh air in, sending it through the heat exchanger and pumps the air to the rooms. The fresh air is preheatd or pre-cooled by the heat exchanger. In addition the central unit is located in the basement. *“The extracting will provide for a continuous airflow through the building. 90% of the heat from the used air is recovered and used to heat the fresh air”* (OeAD,a). Table 9 shown the ventilation system type in the building.

Tab.9 Ventilation system

Centralized/ Semi-central/ Decentralized	Centralized
Heat Recovery	yes
Units	1,2,3 and 4 bedroom
Investment cost per pro. unit	58 euros/m^2
Manufacture for ventilation units	Airvent

Fig.39 Ventilation system

Fig.40 In-Out air deflector (roof)

Fig.41 Ventilation System- room partial view.

3.1.10. Student Housing Building Manual

The Oesterreichischer Austauschdienst Austria Exchange Service office created a building manual for their current passive house projects Molkereistrasse, Kandlgasse and Sechshauserstrasse. The intent of the manual is to inform the students in a very simple and concise way about the passive house function and their contributions of maintaining high standards for this type of building.

Manual sections:
What is a passive house?
Elementary ideas of a passive house
Insulation
Airing of the room
Heat recovery
Passive use of solar energy
Passive pre-heating and cooling of fresh air.

Recommendations to students:

1. Opening the windows is possible when the outside temperature is higher than 10° Celsius.
2. To avoid air problems you must keep the ventilation in- and outlets clear at all times and also clear the bottom of the door where the air flows from room to room.
3. Do not shade the windows during the wintertime or cold seasons to avoid turning on the heating and using the natural light to heat the space. In summer season it is important to use the shading device to avoid high heat gains of the summer days.
4. Keep the room thermostat clear of objects and candles or clothing that can affect the temperature readings of the room.

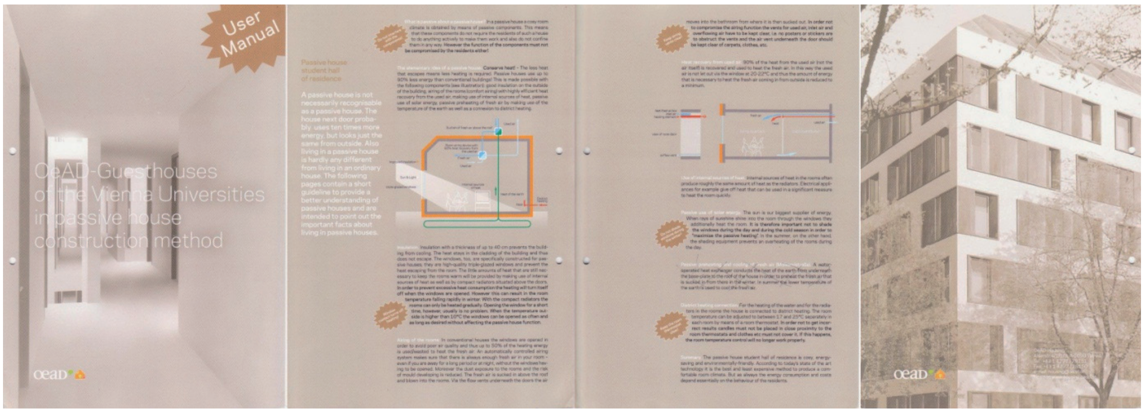


fig.42 OeAD user manual (OeDA,a)

3.2 Measurements

To determine the user’s comfort levels, measurements were obtained of the passive house current environment conditions and getting feedback about the user’s adaptive behavior and comfort of the residents using occupancy evaluations.

The raw measurements were obtained using data loggers devices that measured the temperature, humidity, CO_2 levels of the units throughout the day. The measurement period was for the months of February, March, April and May. In each apartment type, two or more data loggers were placed depending on the amount of bedrooms per apartment. In each apartment the sensors were positioned in the living area and in the sleeping room. The CO_2 sensors were positioned only in the living room area while there were restricted electrical outlets in the apartments been evaluated. In addition temperature sensors were placed in building A hallways and in the main reception office to be able to get readings of possible temperature conditions differences in other sectors of the building A. The units were selected based on the building location, residents living period in the units that will match with the length of analysis period of the study. This was considered important reason while student dormitories have a diverse flow of residents living in the building that could fluctuate through the year.

Data collection period: February 15th, 2011 thru May 11th, 2011

3.2.1. Measuring Devices

The HOBO data loggers were used to read the internal conditions of the units. There were two types of data loggers; one assessed the temperature only and others will assessed temperature, humidity, light and CO_2 measurements. The HOBOS in the hallways measured the temperature only, while the HOBOS in living room/kitchen areas and sleeping bedrooms collected relative humidity, temperature and CO_2 data.

Fig.43 HOBO U12-O12

Carbon Dioxide monitors- Vasala Carbocap GMW22

The monitors were placed in two, three and four unit types. The carbon dioxide measurement range is from 0-2000 ppm. The temperature measurements range from 0°-50° Celsius (+32°-+122° F). The measurements are done by a single-beam, Dualweblenght NDIR sensor. The HOBO U12 is also necessary to be able to collect the data. (Visala-Therm).

fig.44 Vasala Carbocap GMW22

Table 10. Hobos locations and units were based on the following factors:

- Residents living in the unit for the entire period of the research
- The building location. Comparing the south facing main building and east facing courtyard building to find the possible fluctuation of temperature by the amount of natural light coming into each building.
- The amount of residents living in the units.
- In addition Hobos were placed in the floor hallways 6th, 4th, 2nd, 1st and basement.

Tab.10 HOBO locations by floor

KANDLGASSE 30			**HOBOS**	**HOBOS**	**HOBOS**	**CO2 Monitors**
GROUND FLOOR						
Kandlgasse	7*	1	001-349			
1. FLOOR						
Kandlgasse	112	3	101-201	001-327		1
Kandlgasse	118	1	101-259			
2. FLOOR						
Kandlgasse	223	1	201-216			
Kandlgasse	225	1	115-227			
3. FLOOR						
Kandlgasse	342	2	301-213	101-322		
4. FLOOR						
Kandlgasse	451	1	301-255			
5. FLOOR						
Kandlgasse	563	1	121-212			
6. FLOOR						
Kandlgasse	671	3	103-203	101-338	115-226	1
HALLWAY						
Kandlgasse	6th	1	209-209			
Kandlgasse	4th	1	301-260			
TOTAL		15				2

3.3 Analysis

As mentioned earlier the Kandlgasse project building is an infill project. In the distribution of the analysis it was taken into consideration the overall building typology differences between both buildings. The main entrance building is classified in the study as building A and the second wing facing East considered building B. The building circulation at building A is centralized while in building B has an external circulation/ corridors. In addition, building A is a seven-story building while building B is a five-story structure. One of the biggest differences of the two buildings is the orientation. The main building has both units south and north oriented, while the courtyard building or building B has only east facing units. In this case this was considered the best approach to get precise data for both buildings. In the analysis the collected data was independently analyzed per building A and building B and later on combined to evaluate the whole building performance.

3.3.1 Type Analysis

For data anlysis, there formats were used: histograms, psychometric charts, and "PMV and PPD". on table 11 indcates the units selected for the evaluation period per bulding location and apartment size.

Tab.11 units used for analysis

Unit	Type	Building	Unit (#)	Unit (#)	Unit (#)
4 bedrooms	4	A	671		
3 bedrooms	3	A	112		
2 bedrooms	2	A	223		
1 bedroom	1	B	118	225	342, 451,563
Hallway/corridor		A	6th	4th	

3.3.1.1. Comulative Frequency Distribution Graphs

The cumulative distribution graph show the data indicated various ranges of based on probability distribution variables. The data values estimate the frequency in percentage (%) and based on bins intervals. The histograms presented, provide density of data of relative to humidity, temperature and CO_2 and air temperature. A histogram was developed for each analyzed unit for each month in building A and in B building and in one building as a whole.
Table 12 data used for the commulative distribution bins' range for data analysis.

tab.12 Bins for commulative distribution graphs

Temperature		**Bins**
	Entire Period	<19 <20 <21 <22 <23 <24 <25 <26>26
	Winter	<19 <20 <21 <22 <23 <24 <25 >25
	Summer	<19 <20 <21 <22 <23 <24 <25 >25
Relative Humidity		<25 <30 <35<40 <45 <50 <55 >55
CO_2		<400 <600 <800 <1000 <1200 <1400 <1600 <1800 <2000 <2500

The histograms show figure ranges of a total of 8 units. While the building's structure and room typology of buildings A and B is different, the evaluations were done doing an individual analysis by building to later combine the results to find possible common or differential changes as the building operates as a whole. The large apartments with 2, 3 and 4 bedrooms are located in building A, while the units in building B there are 1 bedroom/studios area the living/kitchen and sleeping area are combined in one room. Therefore, figures for building A and B show temperature, relative humidity and CO_2 for the living room and sleeping room but for building B the evaluation is combined while these units are both living/sleeping apartments. See fig 10.

3.3.1.2. Psychrometric charts

The psychometric charts provides a point representation of humid air, where air is composed of oxygen and nitrogen forming water vapor, that will determent the human comfort depending on the surrounding air. The comfort zone temperature is 20°C to 24°C and the relative humidity of the building 30% to 60%

The chart will show the saturation line indicating moisture and in addition it will show the dry bulb temperature. In the Chart the comfort zone is identified by the temperature and humidity parameters. In the study there were some parameters assumed, based on the behavioral activity of the residents, while taking into consideration that most students will be at their dormitories in the afternoon and evening hours. The calculations of the psychometric chart took into consideration winter and summer periods' behavioral variations. The data points that fall in the comfort zone indicate the thermal comfort response.

3.3.1.3. PMV and PPD

Table 13.the calculation of the PMV and PPD assessment of thermal comfort in the building, was used to provide an evaluation of the system’s performance and occupant comfort levels based on the Predicted Mean Vote. The values obtained between -0.5 and 0.5 indicate that the values are a neutral range. The predicted percentage of satisfied shows a quantitative measure of groups of people dissatisfaction in percentages (%). Table 14. Provides thermal comfort levels based on behavioral parameter of the mean radian temperature (MRT) are depended on the metabolic rate of the human body, therefore in the analysis of the PMV the body temperature and Clo value based on the possible students behavior were considered in addition to their activities during the day at night to reach the possible scenarios of thermal comfort. Table 13 shows the values for the summer and winter period based on temperature changes, clothing, time and human activity.

Tab.13 Calculation values of PMV and PPD

		Winter				Summer			
		Feb		March		April		May	
Room	Hours	Clo	V($m \cdot s^{-1}$)	Clo	V($m \cdot s^{-1}$)	Clo	V($m \cdot s^{-1}$)	Clo	V($m \cdot s^{-1}$)
Living /kitchen (LR)	8:00-20:00	1.2	0.1	1.0	0.1	0.8	0.2	0.6	0.2
Sleeping Room (SP)	20:00-8:00	1.6	0.1	1.4	0.1	1.2	0.2	1.0	0.2

On table 14 is shownthermal comfort conditions calculated values determined by levels of dissatisfaction.

Tab.14 Thermal comfort- subjective reactions to air movement (OENORM 7730,2006).

	PMV- account	PPD- account
Cold	-3	99,1
Cool	-2	76,8
Somehow cold	-1	26,1
Neutral	0	5,0
Somehow warm	1	26,1
Warm	2	76,8
Hot	3	99,1

3.3.1.4. Questionnaire

The questionnaire's data is based on a total of 12 responses by students out of the 65 questionnaires sent. The majority of respondents were female students. Additional interviews were done to the current building employees and members of the OeAD housing office Vienna to gain their personal opinion on the building's performance and maintenance. This questionnaire asked questions related to the following:

How much knowledge do they have about passive house? comfort, user habits, ventilation and energy efficiency.

4. RESULTS AND DISCUSSION

4.1. Indoor Environment

For the analysis of the current indoor quality and building performance a comulative frequency distribution data analysis supplies quantitative results for later conclusions. The following list provides a list of abbreviation used during data analysis to obtain consistant and understandable graphs: See also Table 11 for unit locations and unit types per size.

Unit Type 1 (studio) :	T1
Unit Type 2 (two bedroom) :	T2
Unit Type 3 (3 bedroom):	T3
Unit Type 4 (4 bedroom):	T4
Living Room:	L
Sleeping Room:	S
Building A:	A
Building B:	B
Corridors:	Cir

Example: T1 - 118 = T1 - Unit number

4.1.1. Temperature

When doing a comparative analysis of both buildings, it is possible to see that the temperature are generally higher in building A than building B. Building B maintains a constant temperature range thru the whole evaluation period.

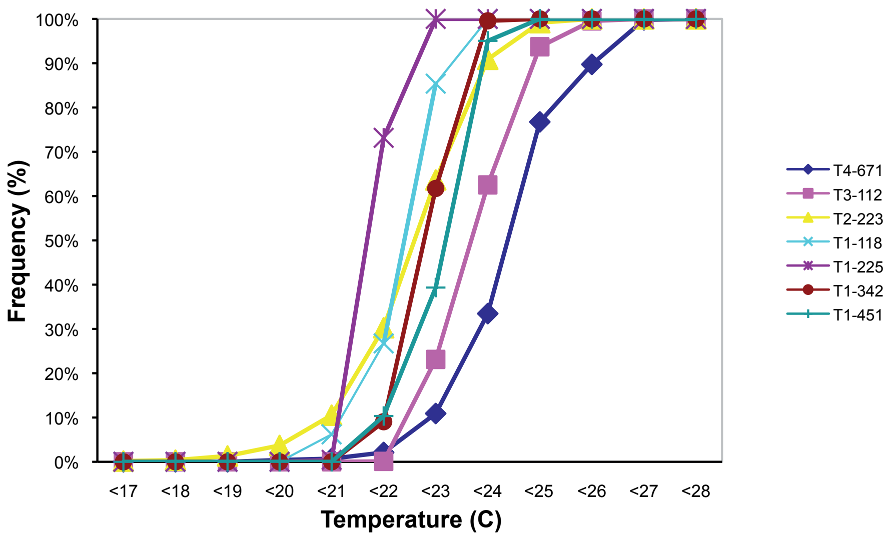


Fig. 45 A + B- All Units- Whole Period

All units show an increase in temperature with the exception of the North facing two bedroom apartment #223. The evaluations of the residents reveals that the students have the tendency to use the blinds to avoid glare in the south-facing units. In building A the results present possibility of higher temperatures at the upper floor during the summer period. In building B facing east – west has may result in less solar gains. It is important to consider that building orientation might have an effect in the internal comfort and temperature levels in a passive house building. Yet the following graphs present that in most of the building units in the summer time maintain comfortable temperature ranges below 24°C.

Building A

The figures 46 thru 50 show the monthly temperature frequency in the living room areas only. The figures illustrate that the temperature increased from low 19°C to 20°C for the winter periods and later increased in the months of April and May. The temperature of the units ranged between 22°C 27° C where unit type T4 maintained very high values.

Especially, it is possible to see this differences in figure 50 where the temperature dropped to the low 22°C as the months of April and May were considerable warm month for this time of the year. This could have been a result of students opening the windows. Also it must be considered that the heat exchanger is not activated during the summer and thefore depended on the outside air temperature.

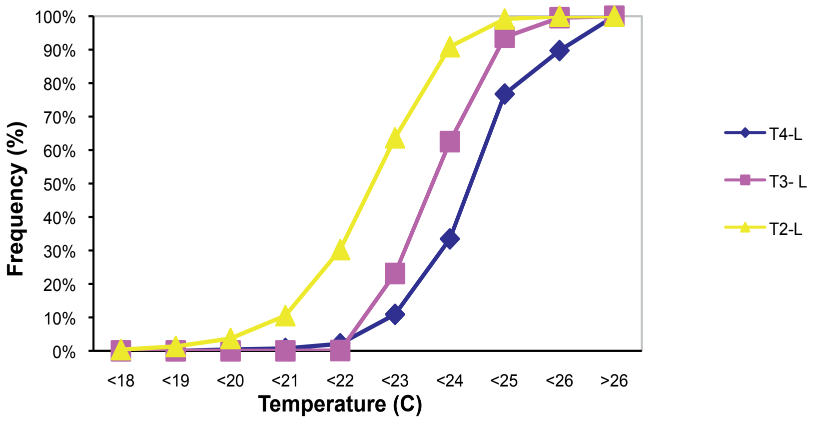


Fig. 46 A - All Units- L - Whole Period

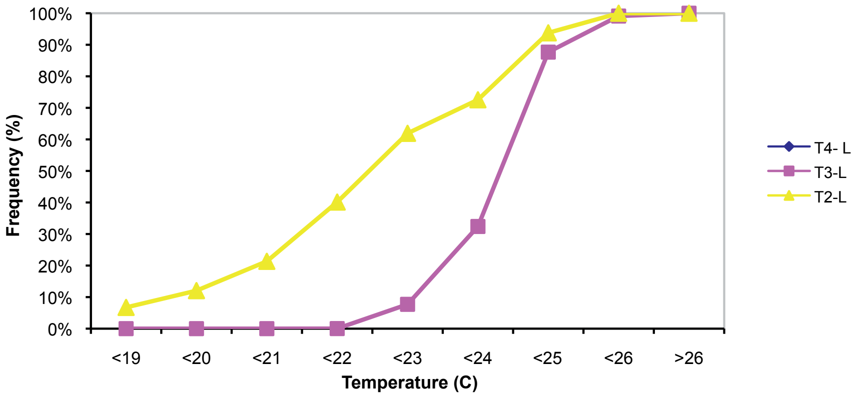


Fig. 47 A - All Units- L-Feb

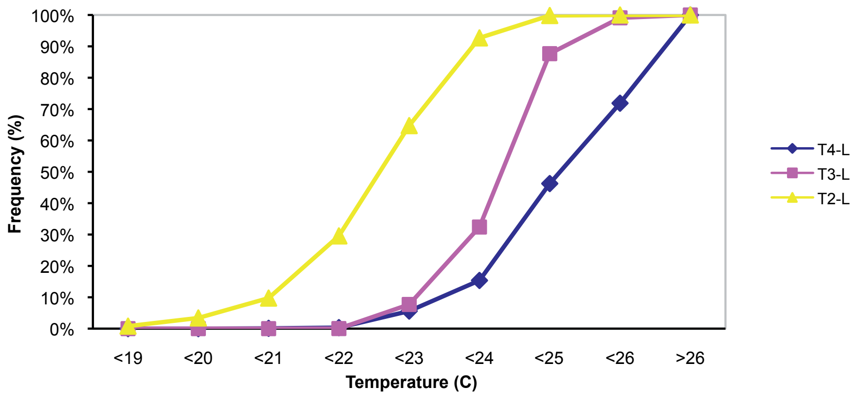


Fig. 48 A - All Units-L-Mar

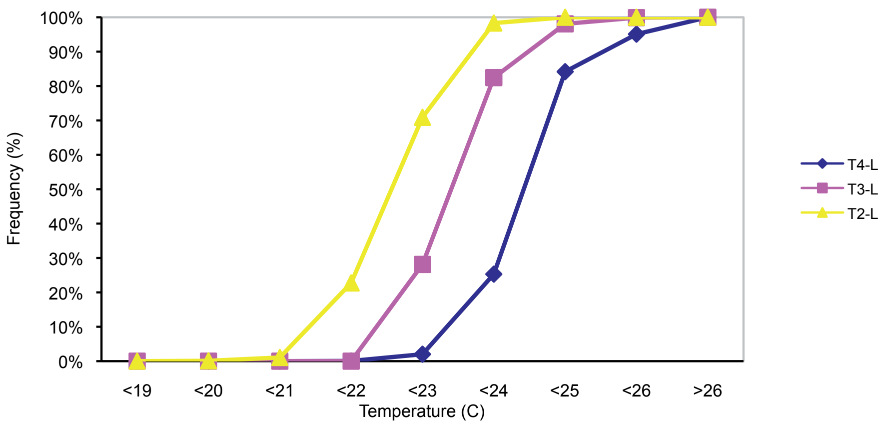


Fig. 49 A - All Units- L-Apr

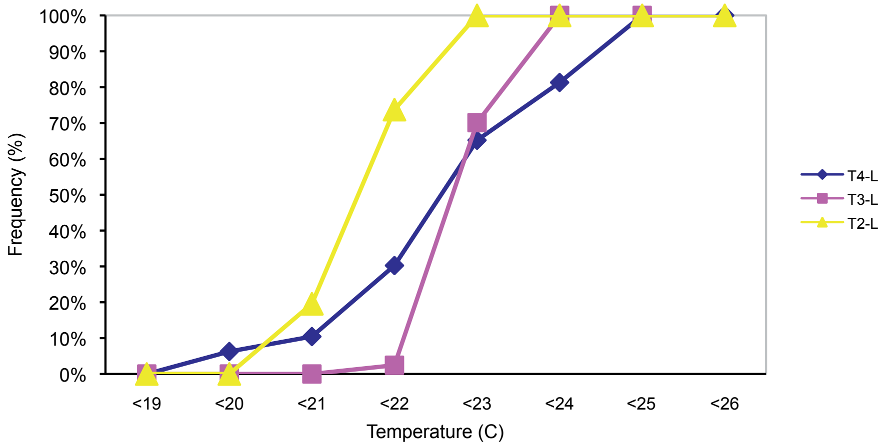


Fig. 50 A - All Units-L-May

in figure 47 the temperature of the month of February in the three units are quite different considering that this is the winter period. In unit 671L the temperature is relatively higher than the other units from 23°C to 26°C. When looking at unit 223L the temperature values remains the same for most o the evaluation period, however the temperature values in the month of February range from 19°C to 24°C which are considered acceptable temperature ranges. In the evaluation period for the living room the overall temperature is always much higher in unit 671L. Considering that this unit is located in the top floor of the building and is facing south influence the temperature values of the apartment by possible solar gains. The result may show be accounted to user behavior by the use of radiators in the units. Building A temperatures from February to March is 10-20% higher than temperatures from April thru May. This result present the possibility that while outdoor temperatures during the month of April and May students open their windows for natural air access that brought the temperature levels between 20°C to 24°C.

Building B

Figure 51 shows values of building B studio apartments for the whole period of observation. The graphs present similar temperatures between 20°C to 24°C. It is clear that temperature levels in building B are one two degrees lower than building A. It maintains a stable higher temperature during the observation period. See figure 45

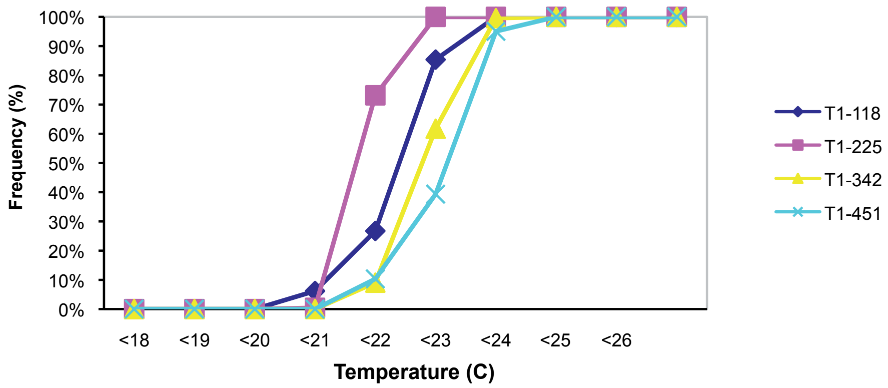


Fig. 51 B - All Untis- Whole Period

In figures 52 thru 55 Building B the living room/sleeping room temperatures range from 20°C to 24°C and the reamain in the same range for each month during the evaluation period. It Indicates that building B maintained constant temperature values with in a resonable range during the entire analysis period.

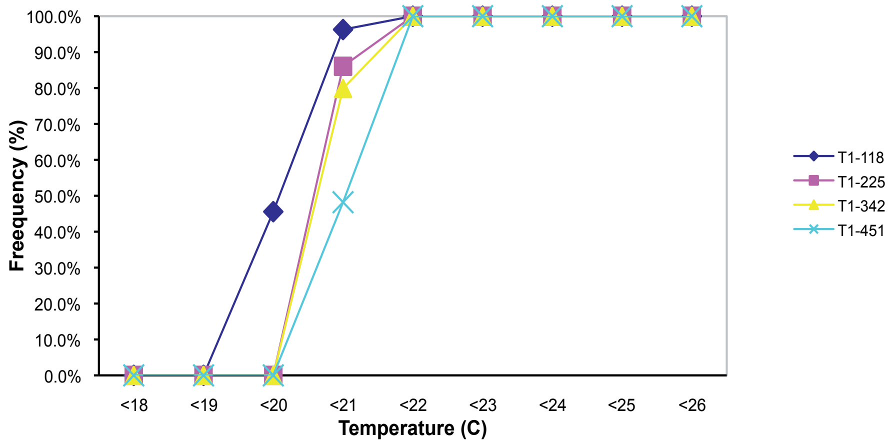


Fig. 52 B - All Units-Feb

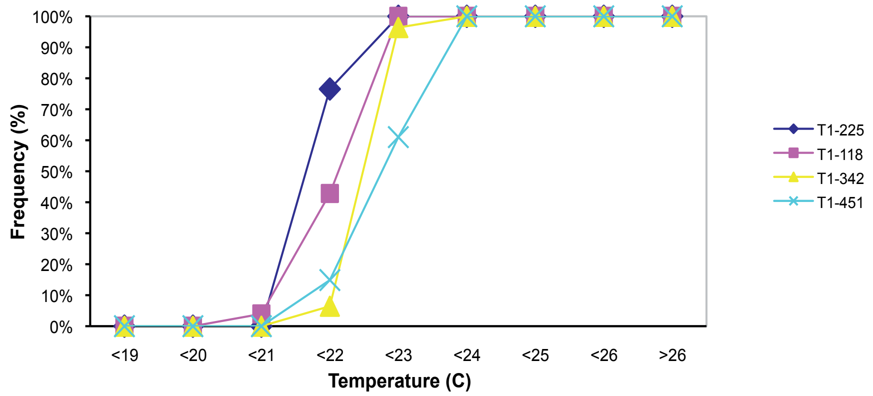


Fig. 53 B - All Units- Mar

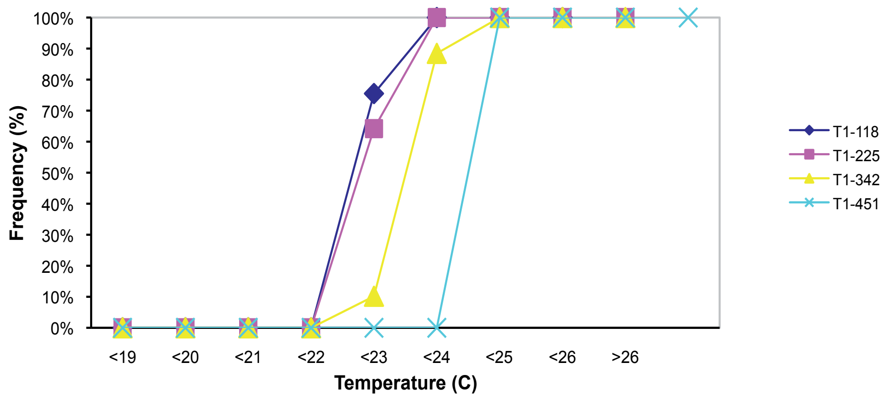


Fig. 54 B - All Units- Apr

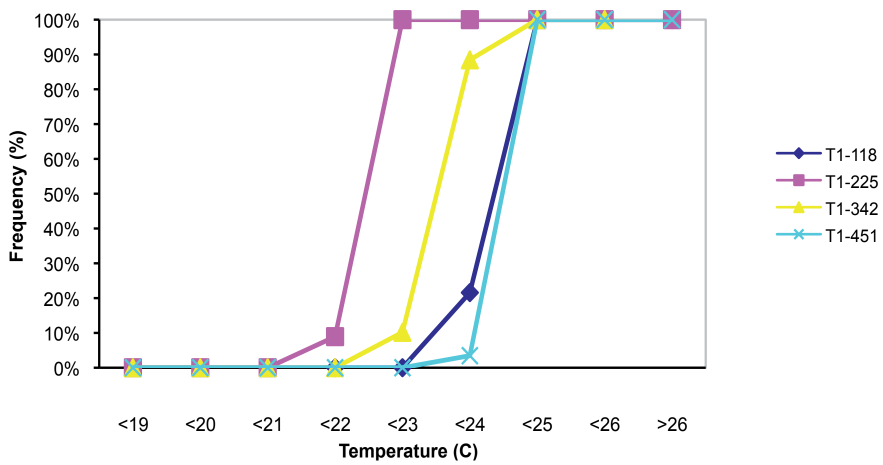


Fig. 55 B - All Units - May

Building A Internal Circulation Corridors

In the evaluation two hobos were placed in the hallways/corridors of building A to measure if the temperature ouside the units had big value differences. In Figures 56-60 the results show that there is little to none temperature fluctuation and values remained between 22°C to 24°C indicating not considerable heat exchange losses in these areas.

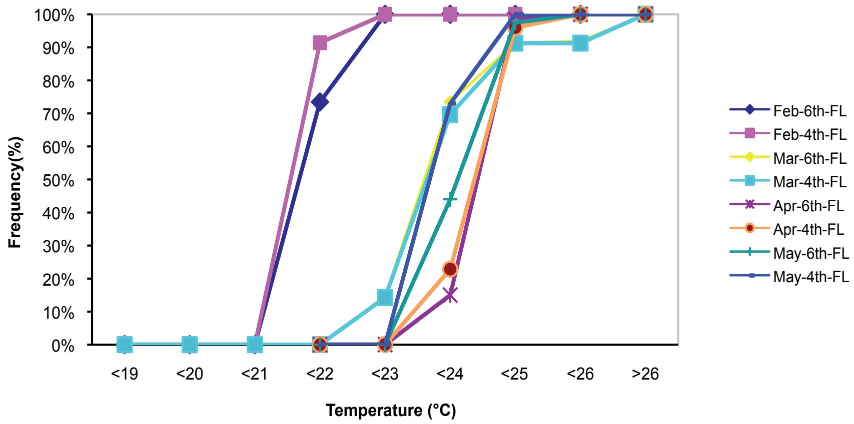


Fig. 56 A - C- Whole Period

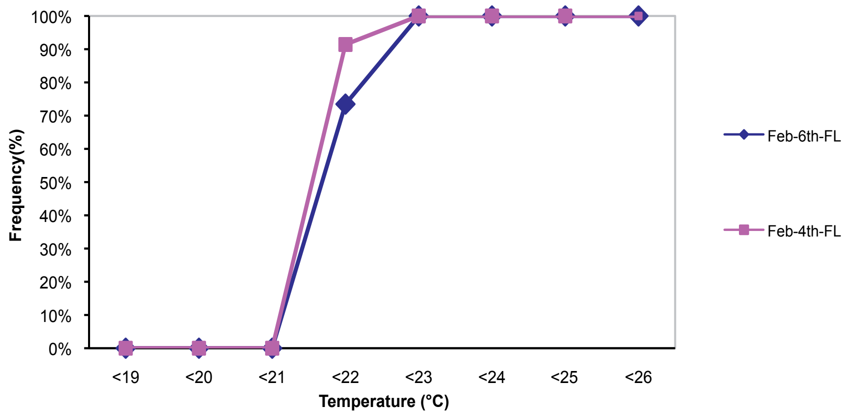


Fig. 57 A - Cir- Feb

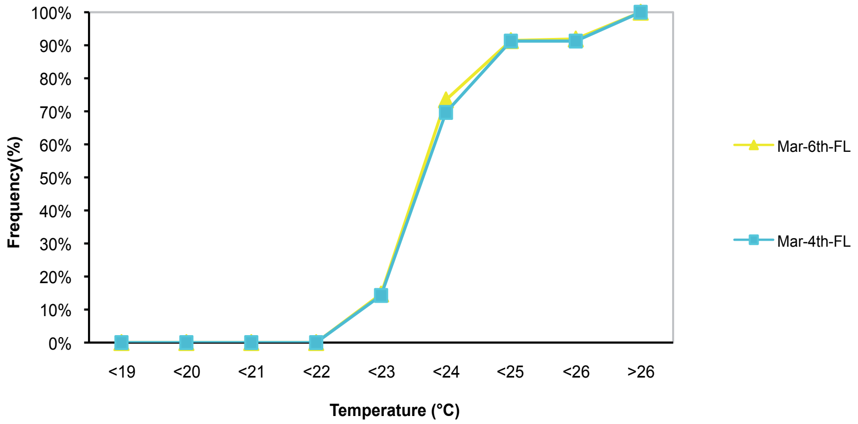


Fig. 58 A - Cir-Mar

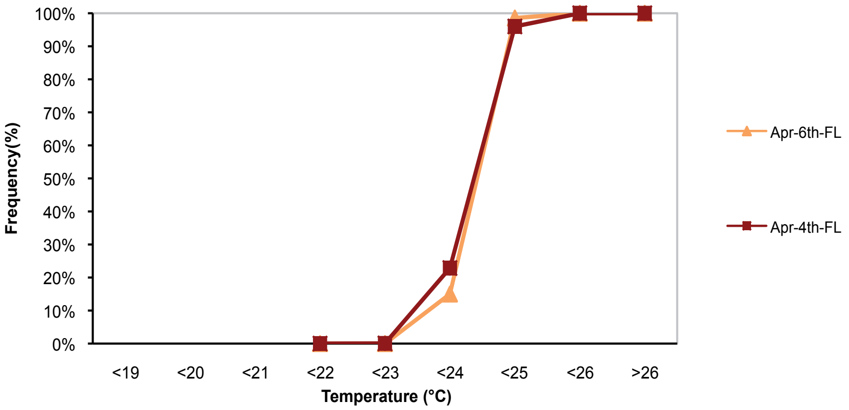


Fig. 59 A - Cir-Apr

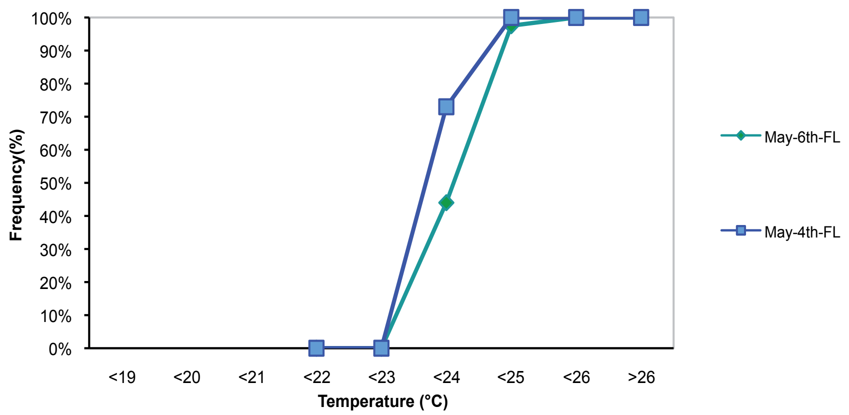


Fig. 60 A - Cir-May

4.1.2.Relative Humidity

Overall Comparison

In figure 61 the building comparison of building A and B the relative humidity values show that most of the units have relative similar values between low 30% and low 40%. In the centralized ventilation could be a factor while the exchanger needs to provide both cold and hot air into the room it could result in the reduction of fresh air volume and and making the indoor air too dry. However, the values are still in a normal comfort range. Take note that complete data for unit 112 was not evaluated while in the beginning there was not consistant reading for the entired period.

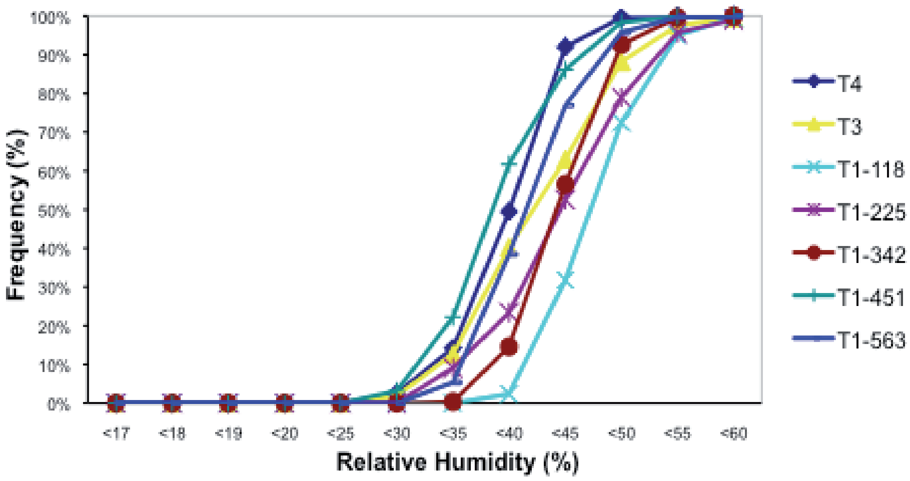


Fig.61 A+ B- All Units-Whole Period

Building A

In the shown figures 62-65 all units present an increase in temperature with the exception of the two bedroom apartment 223 which is the unit that is facing North while the others are facing south. In the evaluations noted by residents students had the tendency to use the blinds to avoid glare problems in these units.

In building A there is a possibility that the temperatures could be higher for units in the upper floor, because in the summer period, the building is receiving solar heat in the south facing wall. in comparison with building B, where there building is facing east – west and is in between two building that can eliminate higher solar gains. It is important to consider that building orientation is a factor in comfort and temperature levels in a passive house building.

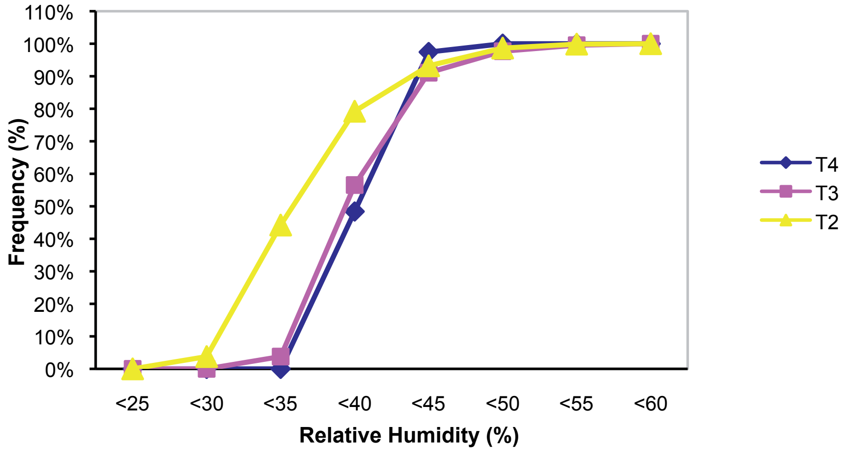


Fig. 62 A - All Units-Feb

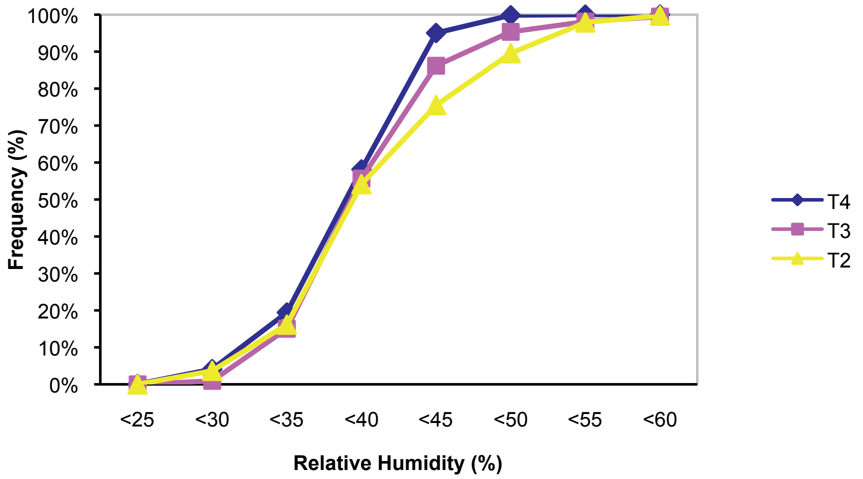


Fig. 63   A - All Units-Mar

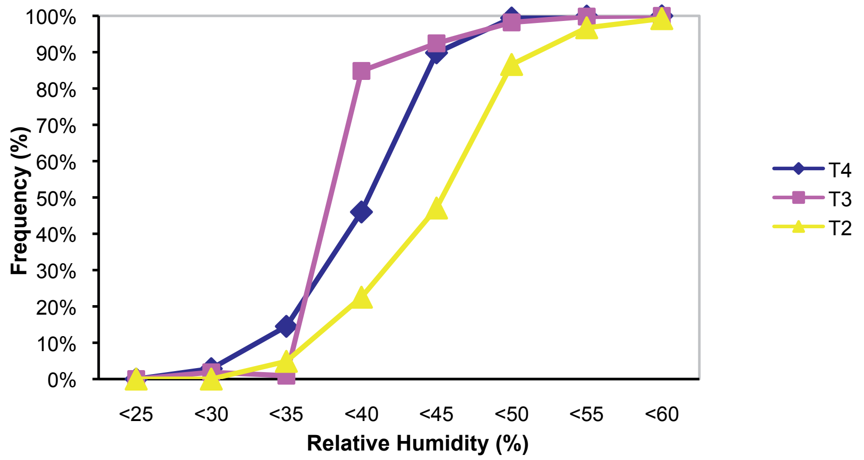


Fig. 64   A- All Units- Apr

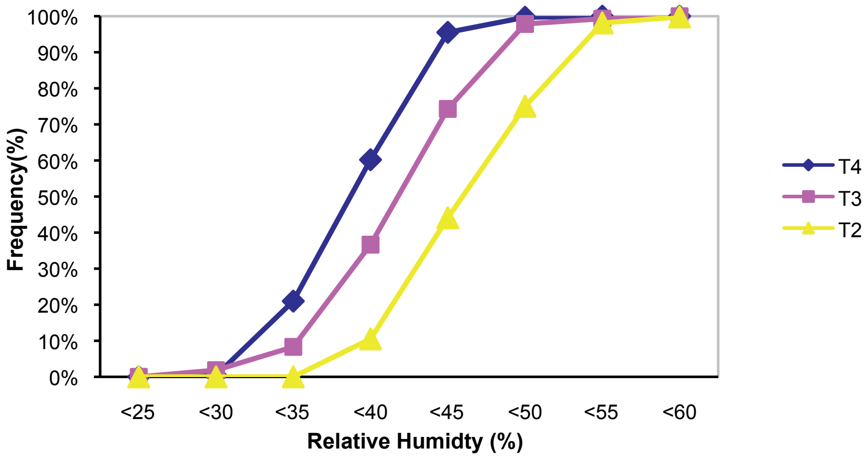


Fig. 65 A - All Units-May

Relative humidity acceptable comfort values are between 30% and 60% based on (Sterling, Arundel, & Sterling,1985). In Figures 62 thru 65 for building A show the relative humidity values have not significant differences throughout the whole evaluation period however as The temperature values in the units increased the relative humity did as well.

For instance, in the month of April and May, in building A, 50% to 60% humidity values are between 40% to 55%, while in earlier months such as February the relative humidity is lower, falling in the range of 30 % to 50%, and then not considered a drastic difference between each month. During the winter period the indoor air could dry as a result of the ventilation system. The ventilation system needs to provide a constant air supply to reduce air pollution.

Building B

In building B it is revealed in figures 66 thru 69 that the relative humidy in the winter period is lower than in the summer period. In most units the relative humidity values are between 30% to 45%. In the month of march Unit 451 has some of the lowest relative humidity values from 25% to 40% and get slightly higher but still at lower than the rest of the units.

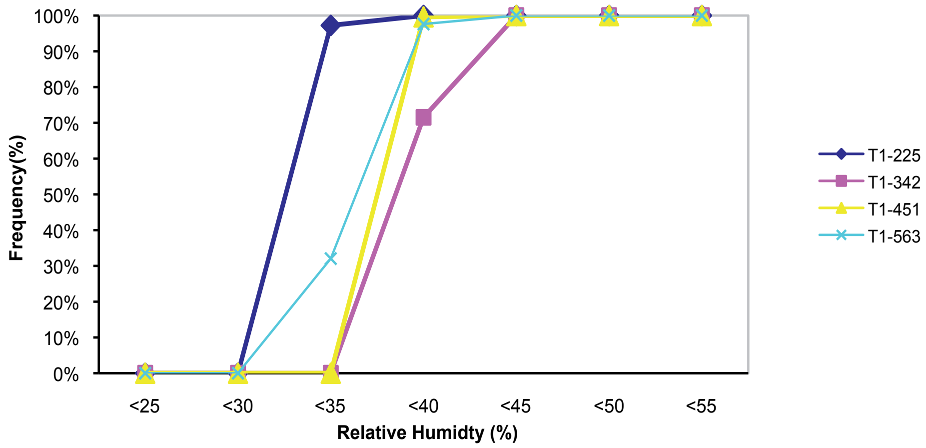


Fig. 66 B - All Units-Feb

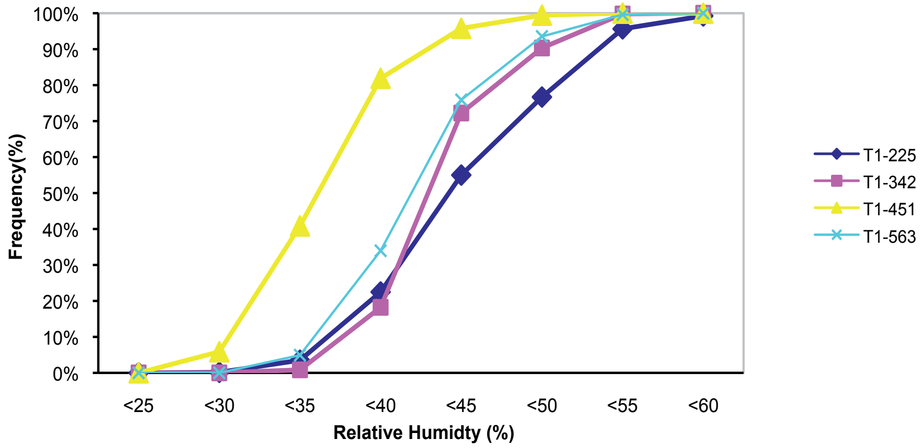


Fig. 67 B - All Units-Mar

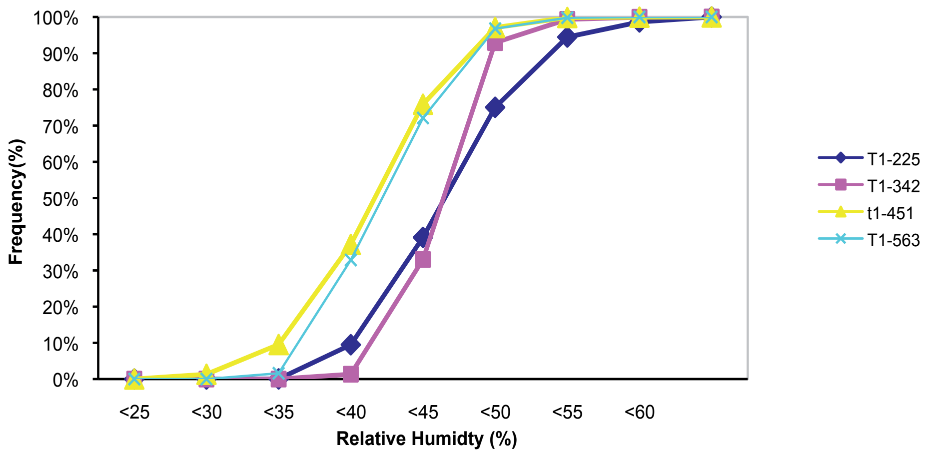


Fig. 68 B - All Units-Apr

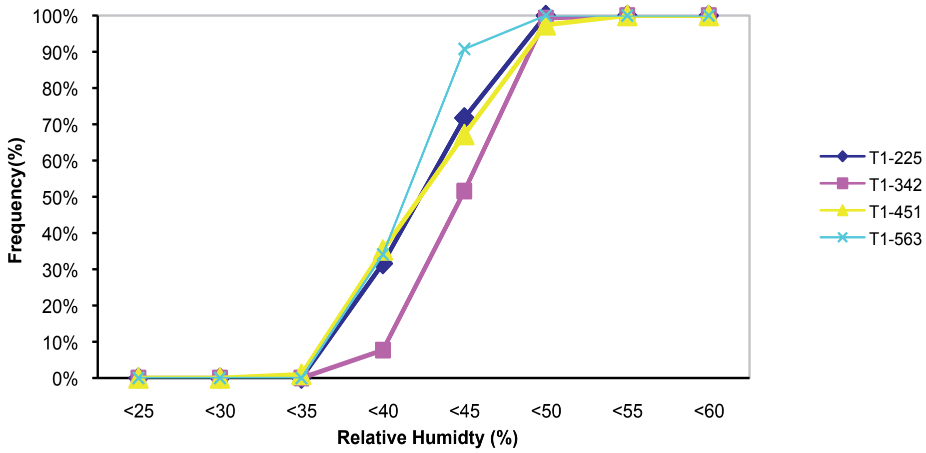


Fig. 69 B - All Units-May

4.1.3. Psychometric Charts

Overall Comparison

Table 15 and table 16 show the thermal conditions of the apartments per building. The results indicate the values points that are often withing the defined comfort zone for buildings A and B. On the other hand, building A results demostrate that the apartment Icoated in building A are in average 70% within the defined comfort zone. When looking at figures 73- 78 for the months of March and April the temperatures are higher and therefore outside comfort zone levels. This could indicate that the units' indoor temperature were much higher because of exterior heat gains or the use of radiators in the units. In building B the 98% of time the indoor temperatures are within the comfort zone levels indicating the temperature proportion are constant and much more stable than in building A units.

Tab.15 thermal conditions within comfort zones (%) for building A

Month	Units		
	671	112	223
February	94	100	58
March	7	33	85
April	23	83	85
May	76	98	56
Whole Period	71.5	78.5	71

Tab.16 thermal conditions within comfort zones (%) for building B

Month	Units				
	118	225	342	451	563
February	100	100	100	100	100
March	98	98	97	90	89
April	100	97	98	96	80
May	99	100	100	100	100
Whole Period	99.2	98.7	98.2	96.5	92.5

Figures 70 -78 show the day and night values for apartment 671 temperature values are out of range or outside the comfort zone 70 to 93% both thru the day. Th rapid change of temperature during the months of March and April may note that students kept higher tempeture in the room at by using the unit's radiators. It can justify that the higher temperatures during the day are a result of the current solar heat gains to this apartment while there is a clear differentiation of % comfort zone values between units from apartment B and apartment A.

Building A
T4-671

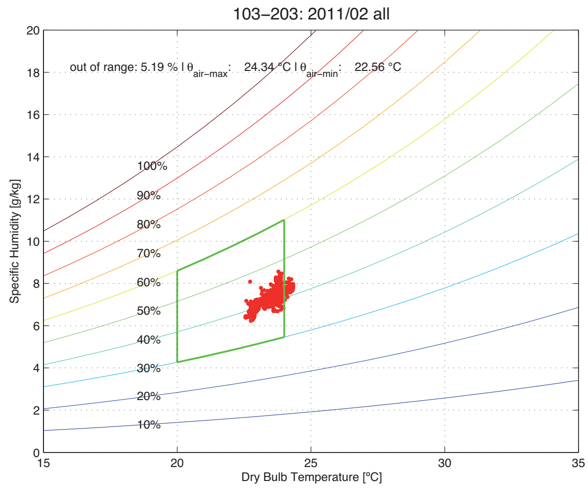


Fig. 70 A- T4-671-L-Whole Period-Feb

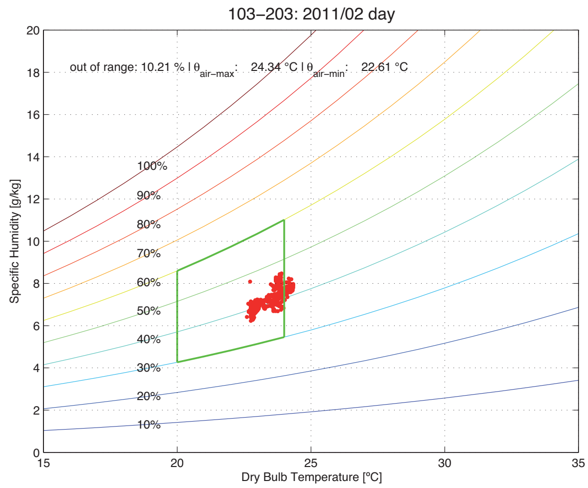


Fig. 71 A - T4-671-L- Day-Feb

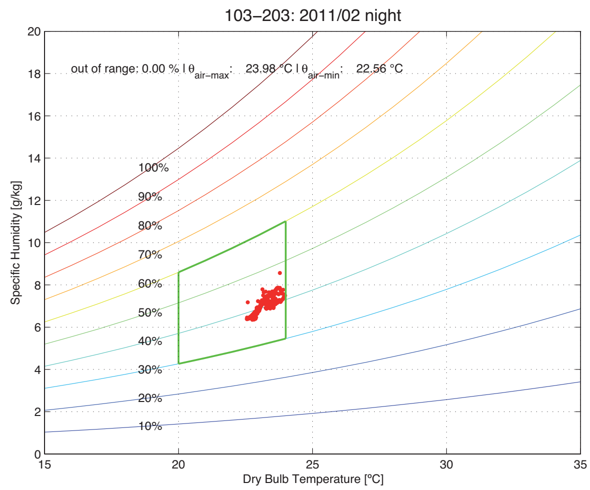


Fig. 72 A - T4-671-L-Night-Feb

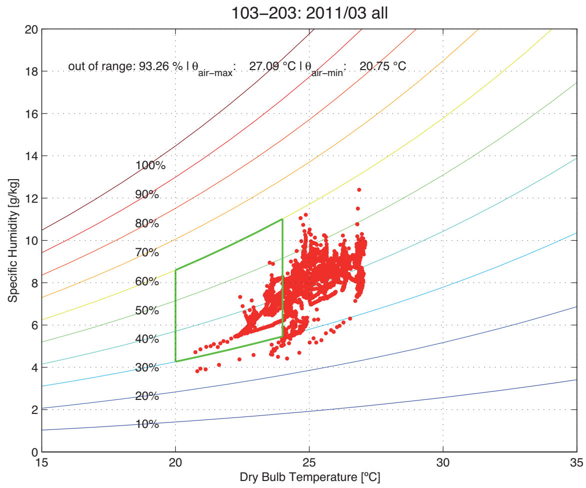


Fig. 73 A - T4-671-L- Whole Period -Mar

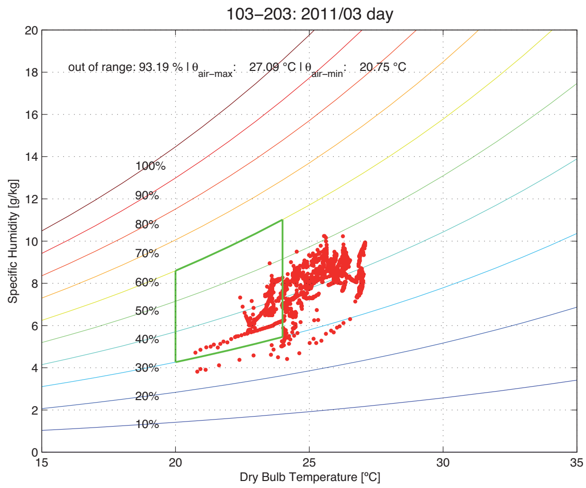


Fig. 74 A - T4-671-L-Day-Mar

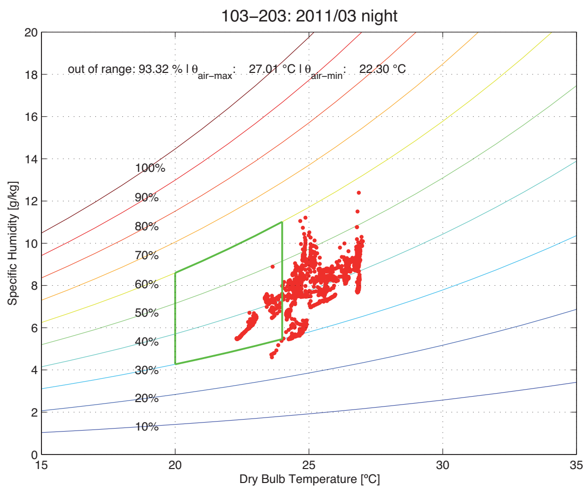


Fig. 75 A - T4-674-L-Night-Mar

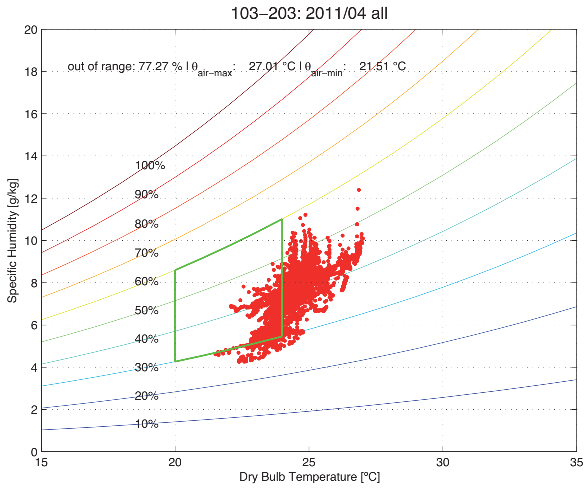


Fig. 76 A - T4-671-L-Whole Period -Apr

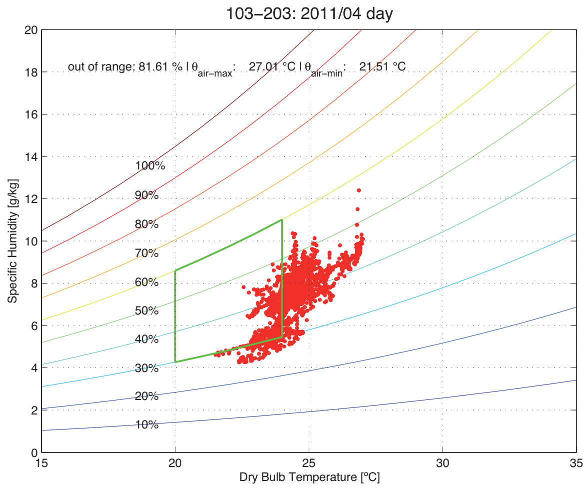


Fig. 77 A - T4-671-L-Day-Apr

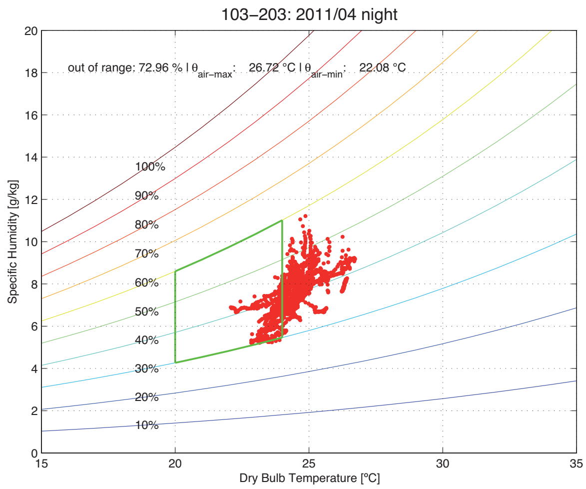


Fig. 78 A - T4-671-Night -Apr

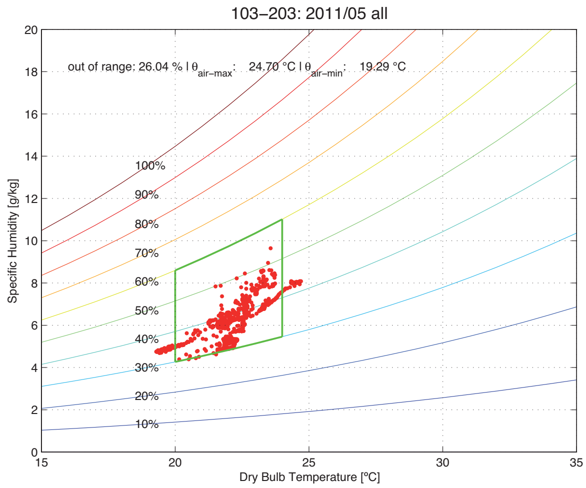


Fig. 79 A- T4- 671-L-Whole Period-May

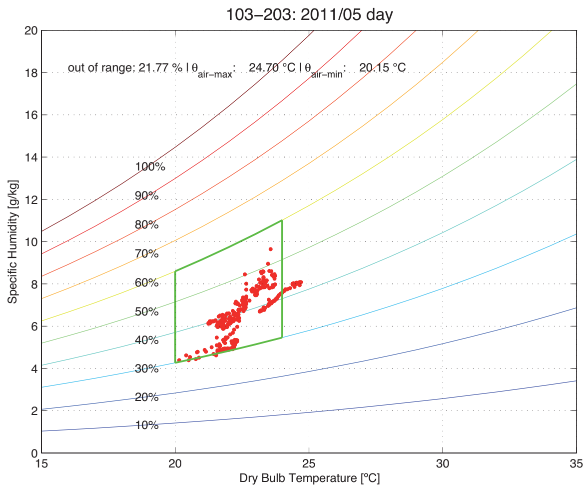


Fig. 80 A - T4-671-L-Day-May

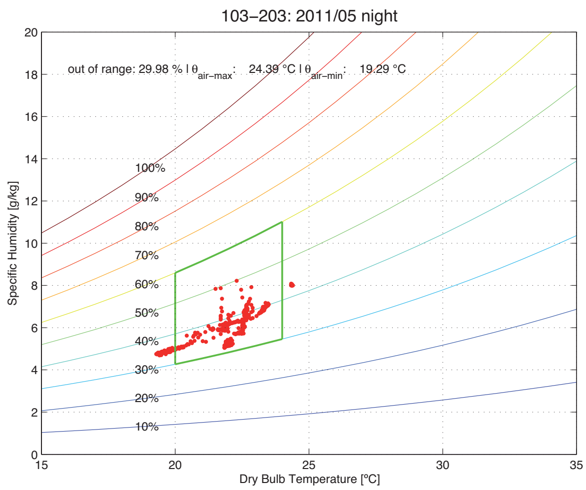


Fig. 81 A- T4-671-L-Night-May

T3-112

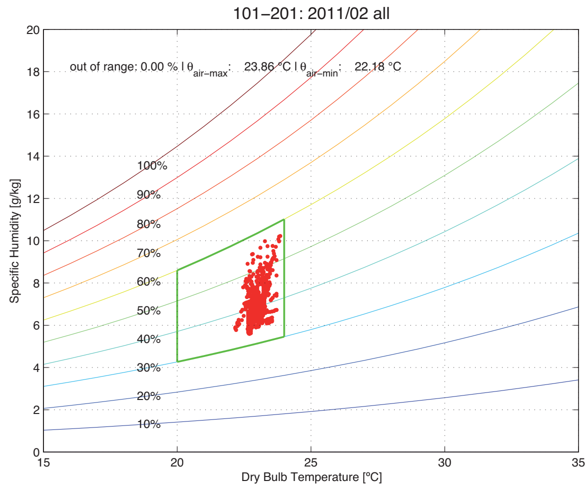


Fig. 82 A - T3-112-L-Whole Period -Feb

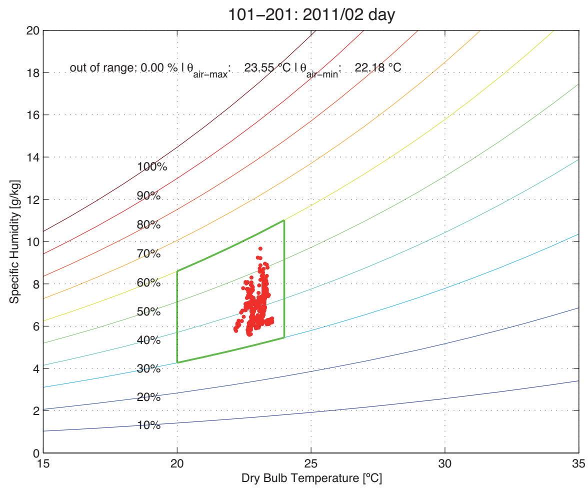


Fig. 83 A- T3-112-L-Day-Feb

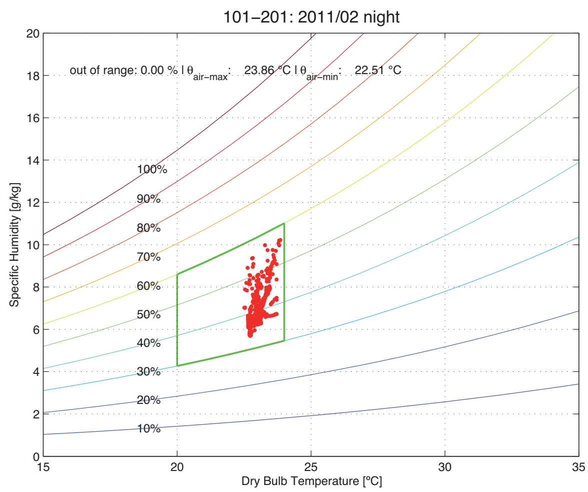


Fig. 84 A - T3-112-L-Day-Night-Feb

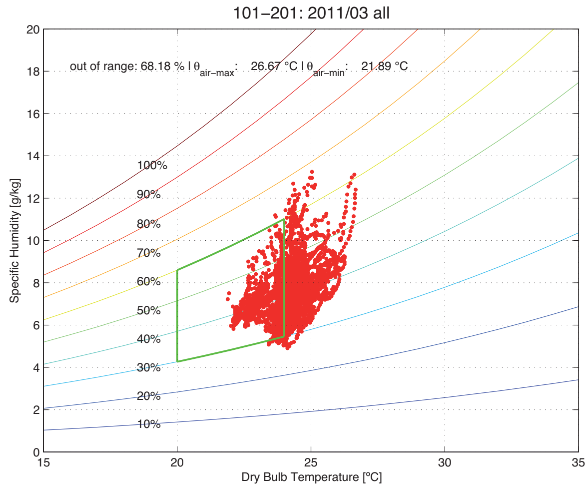


Fig. 85 A - T3-112-L-Whole Period-Mar

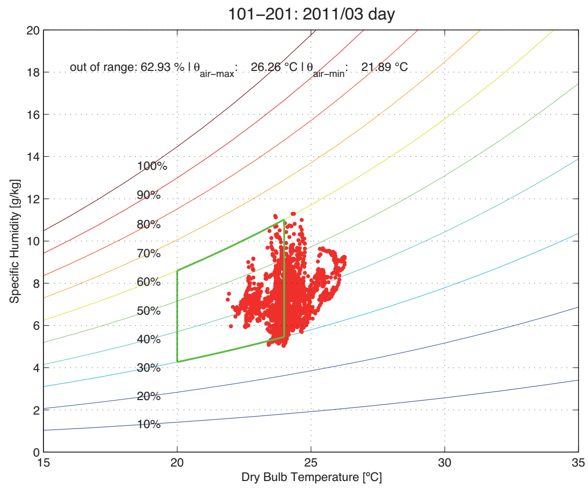


Fig. 86 A - T3-112-L-Day-Mar

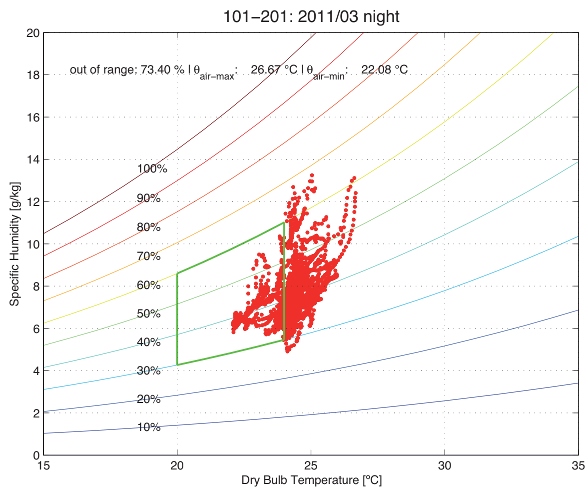


Fig. 87 A - T3-112-L-Night-Mar

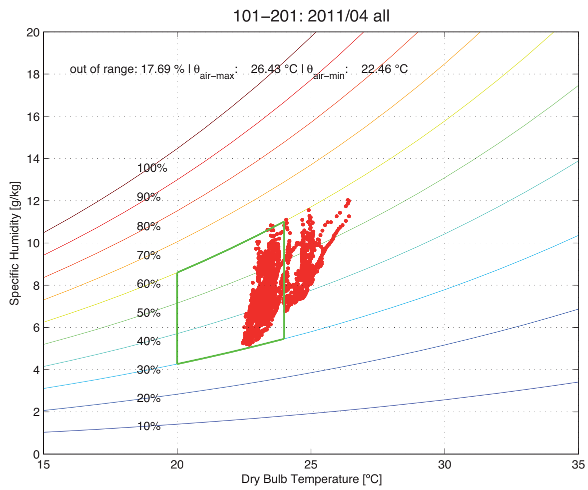


Fig. 88 A - T3-112-L-Whole Period-Apr

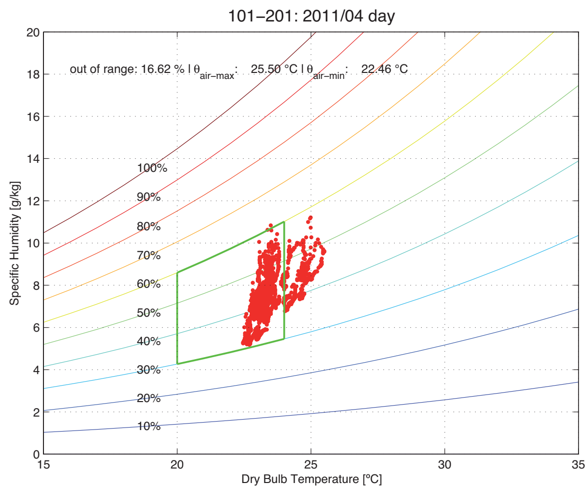


Fig. 89 A - T3-112-L- Day-Apr

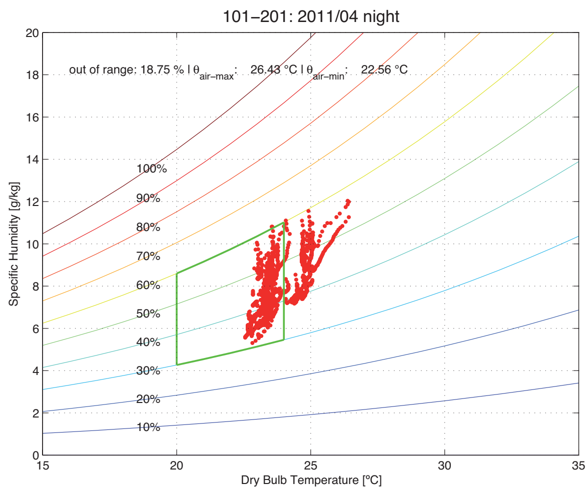


Fig. 90 A - T3-112-L-Night-Apr

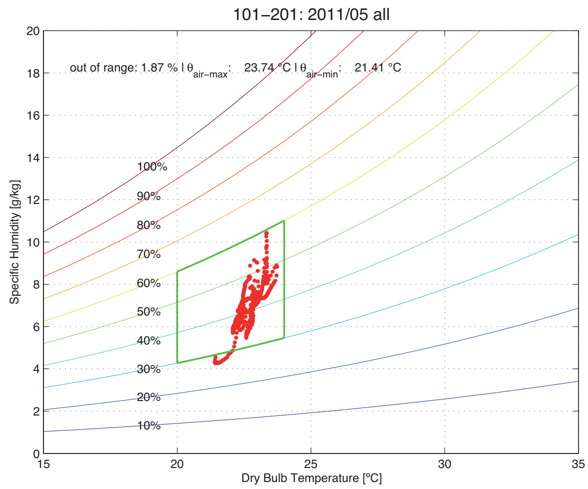


Fig. 91 A - T3-112-L-Whole Period-May

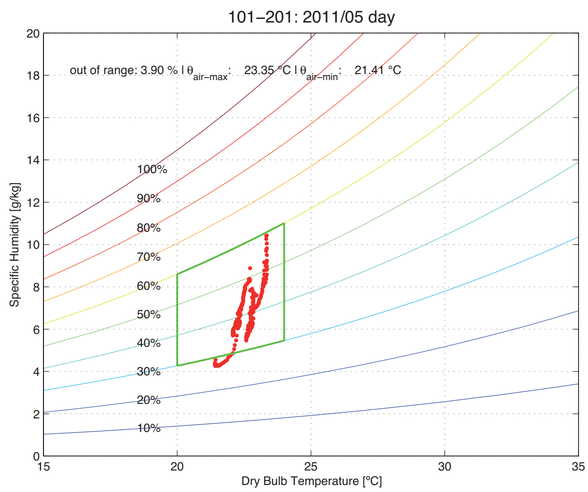


Fig. 92 A - T3-112-L-Day-May

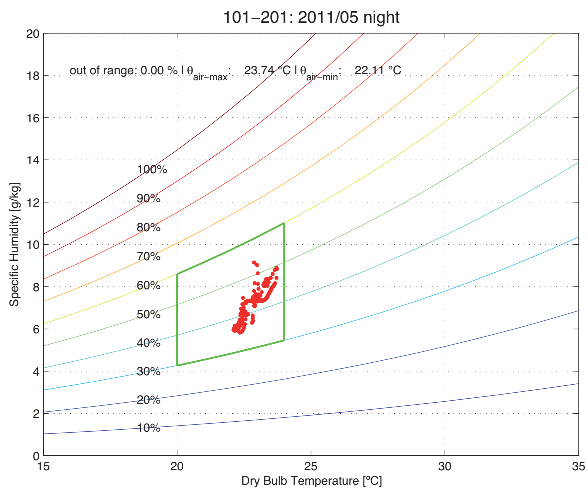


Fig. 93 A - T3-223-L-Night-May

Figures 85-90 for unit 112 show that in the overall results of the living room temperatures for the months of March and April are outside the comfort zone reach temperatures of 24°C and 27°C. Yet in the months of May temperature values dropped suggesting that as the outdoor temperature increased students were able to open the windows and the indoor temperature could regulate itself. The data collected during the day and night period show not great difference between each period.

Building B

In relation to the thermal conditions of building B the temperature and humidity percentages are within the comfort zone. In comparison with the day and night conditions of the units the temperatures inbuilding B did have visable changes in temperature as building A where temperatures increased no more than one degree during the night. See additional figures in the Appendix for the rest of elevaluated units in building B.

T1-118

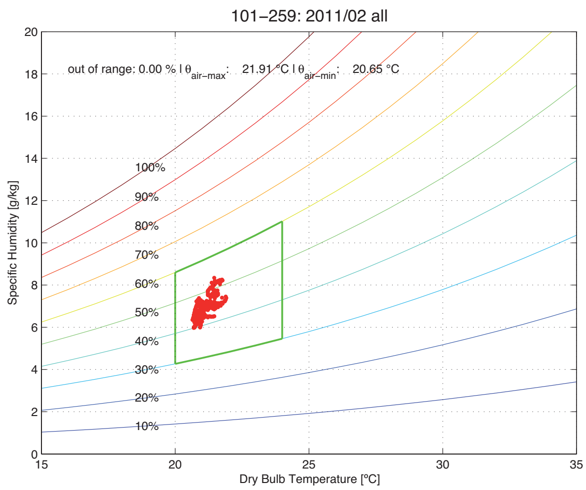


Fig. 94 B - T1-118- Whole Period -Feb

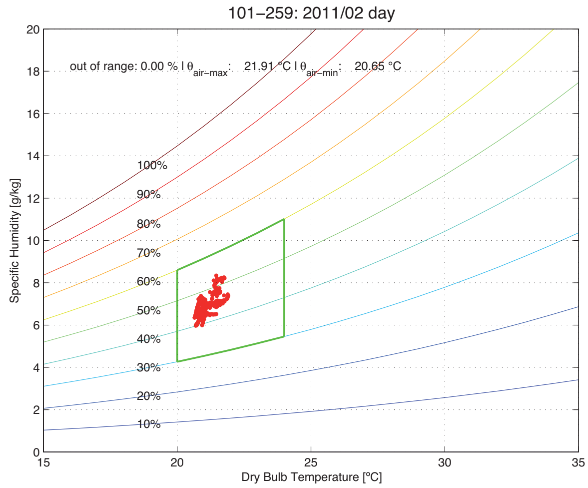


Fig. 95 B - T1-118- Day -Feb

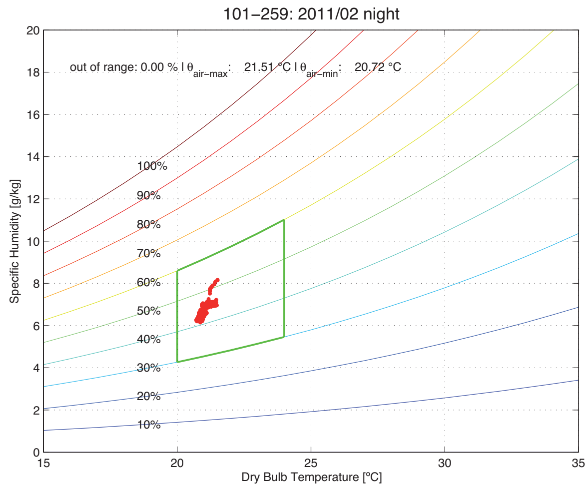


Fig. 96 B - T1-118-Night -Feb

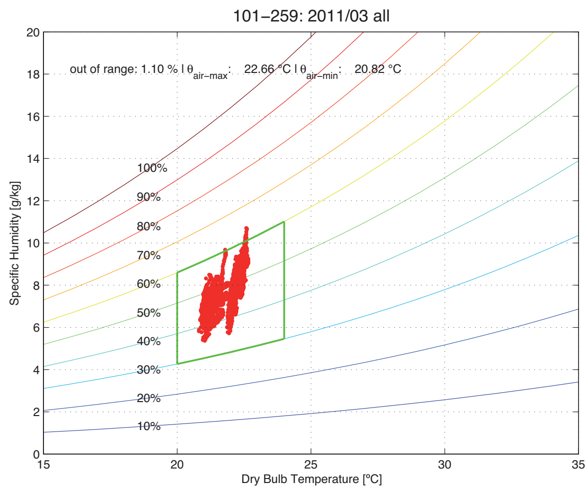


Fig. 97 B - T1-118-Whole Period-Mar

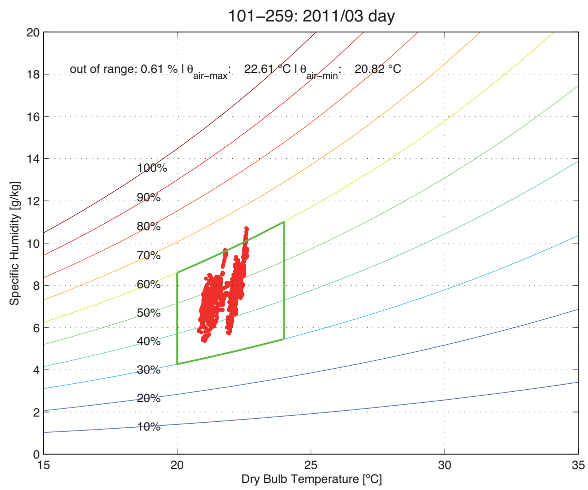


Fig. 98 B - T1-118-Day-Mar

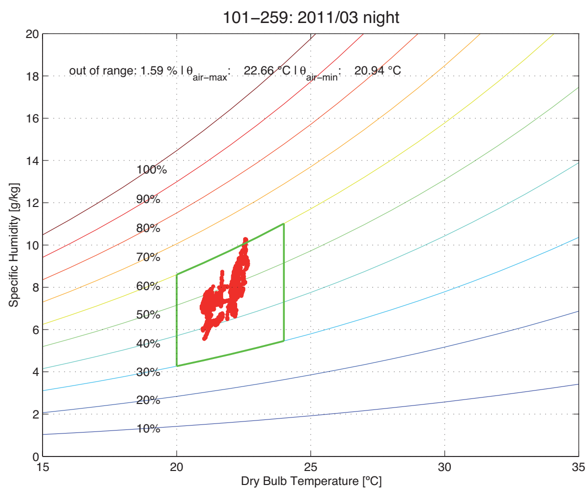


Fig. 99 B - T1-118-Night-Mar

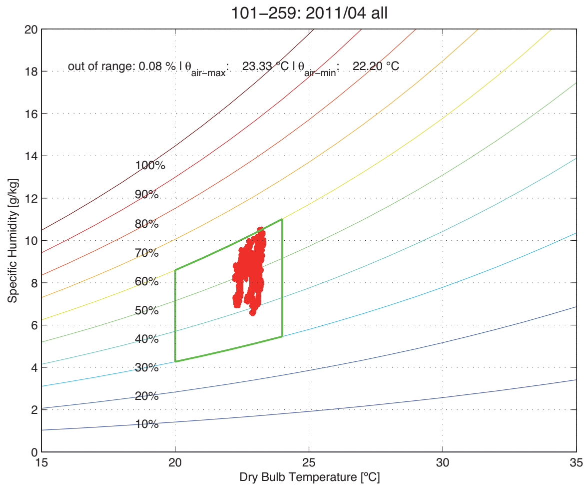


Fig. 100 B - T1-118-Whole Period-Apr

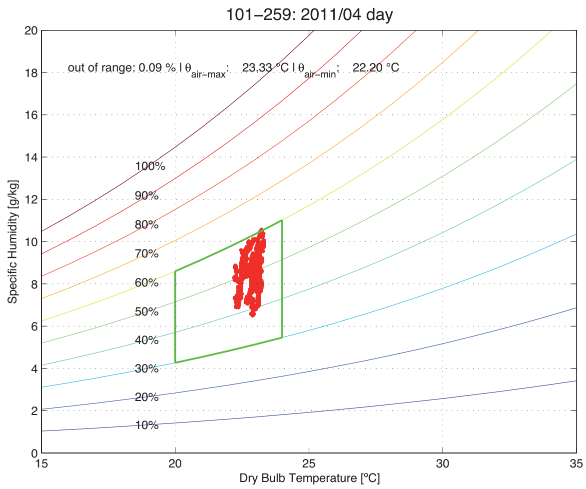


Fig. 101 B - T1-118-Day-Apr

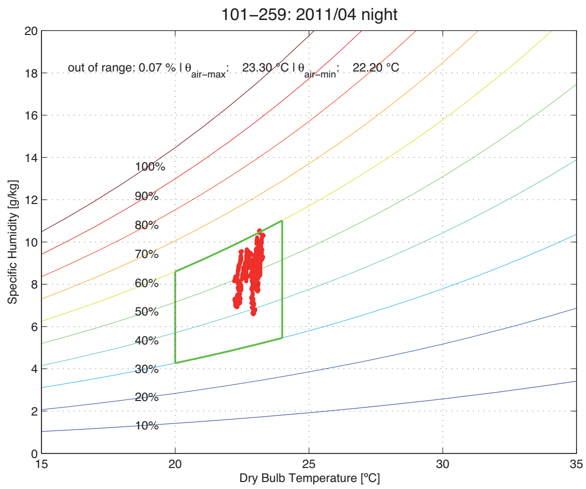


Fig. 102 B - T1-118-Night-Apr

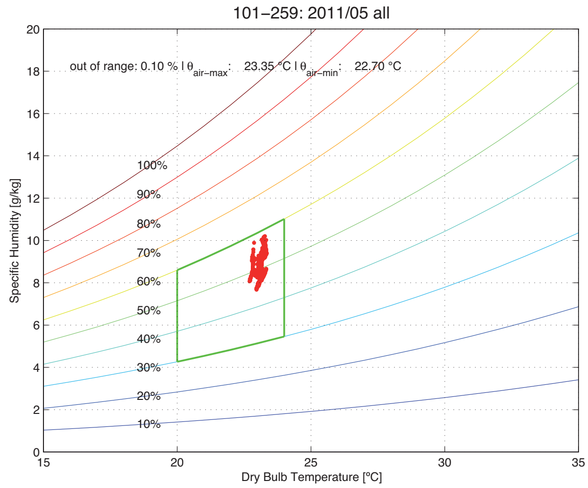


Fig. 103 B - T1-118-Whole Period-May

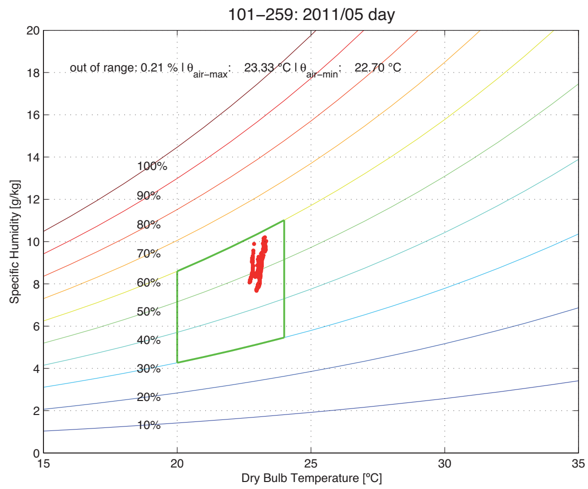


Fig. 104 B - T1-118-Day-May

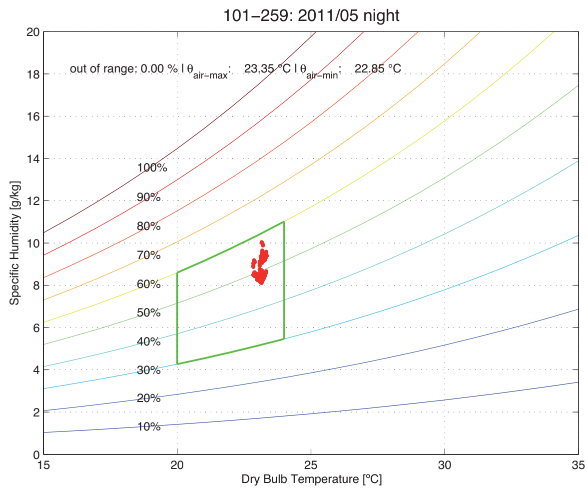


Fig. 105 B - T1-118-Night-May

T1-225

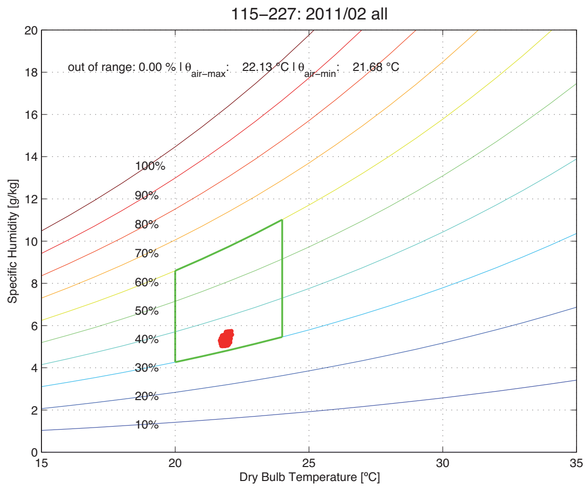


Fig. 106 B - T1-225-Whole Period-Feb

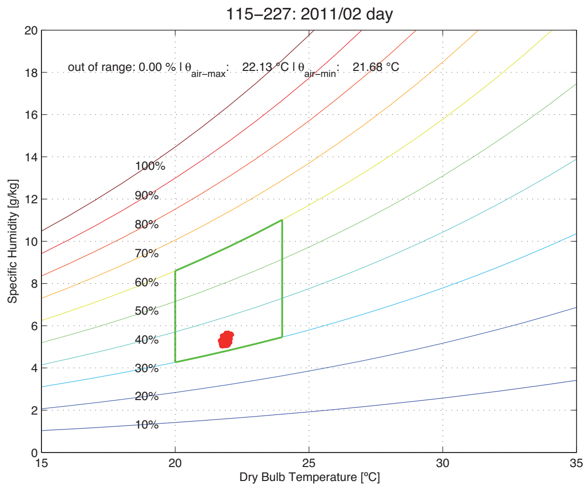


Fig. 107 B - T1-225-Day-Feb

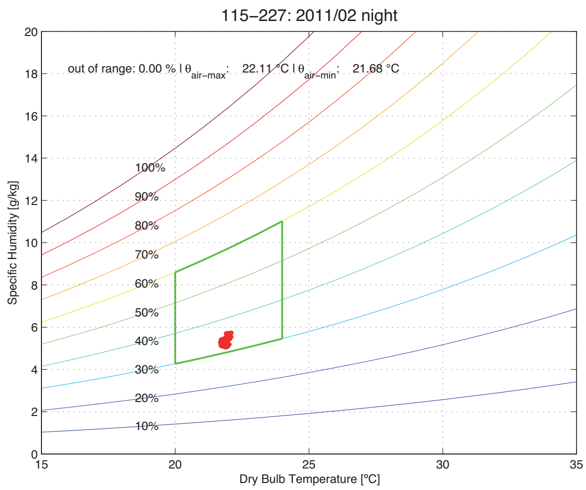


Fig. 108 B - T1-225-Night-Feb

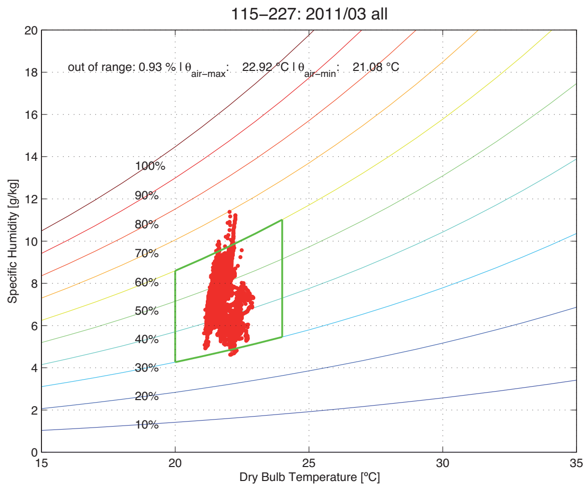


Fig. 109 B - T1-225-Whole Period-Mar

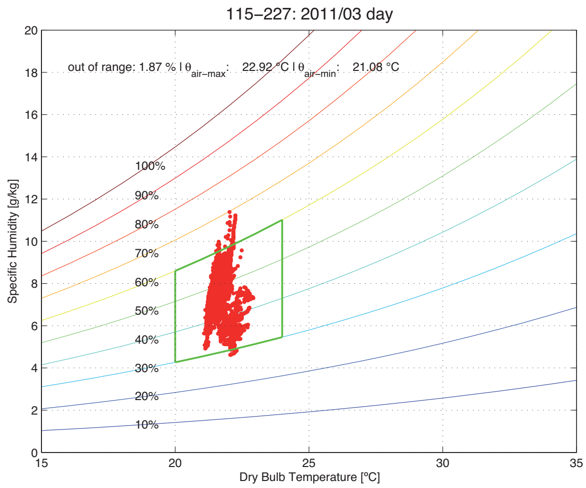


Fig. 110 B - T1-225-Day-Mar

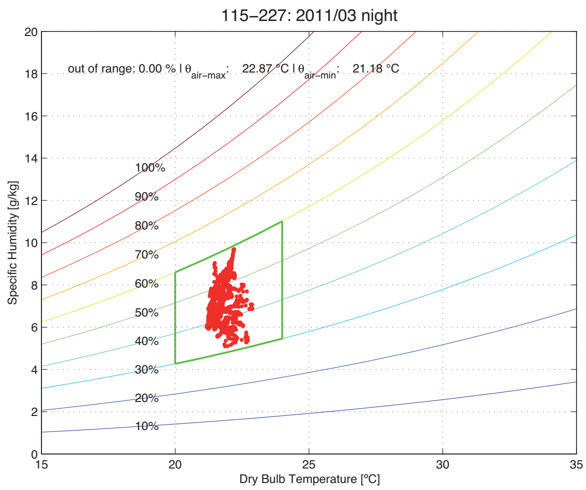


Fig. 111 B - T1-225-Night-Mar

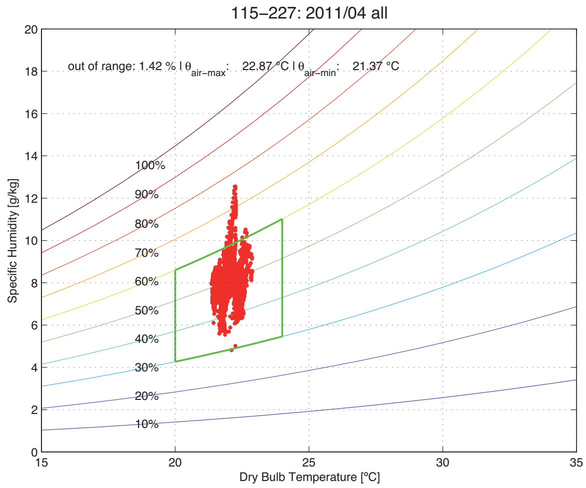


Fig. 112 B - T1-225-Whole Period-Apr

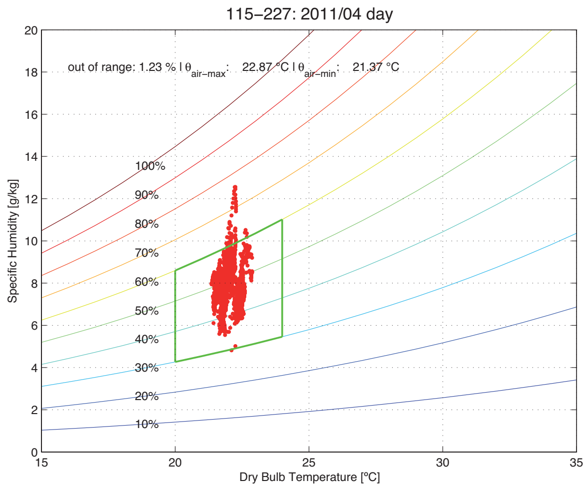


Fig. 113 B - T1-225-Day-Apr

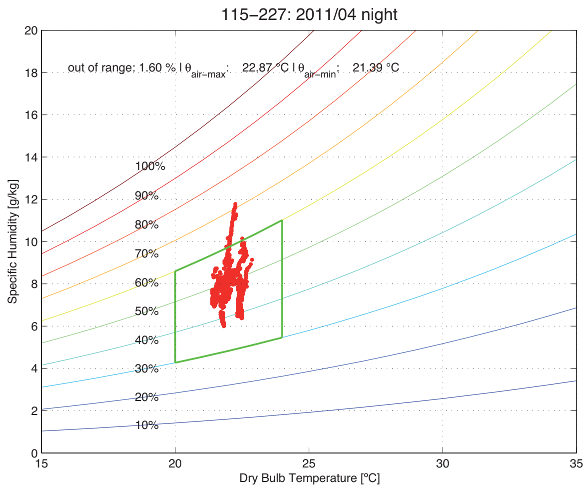


Fig. 114 B - T1-225-Night-Apr

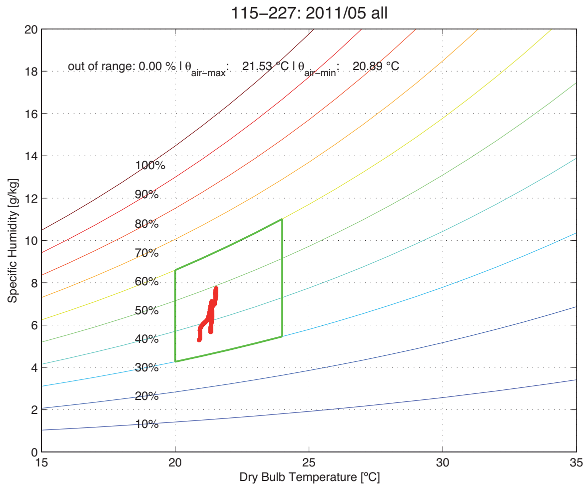


Fig. 115 B - T1-225-Whole Period-May

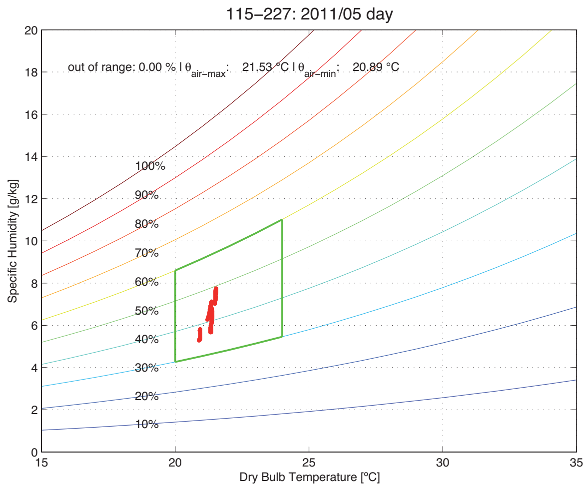


Fig. 116 B - T1-225-Day-May

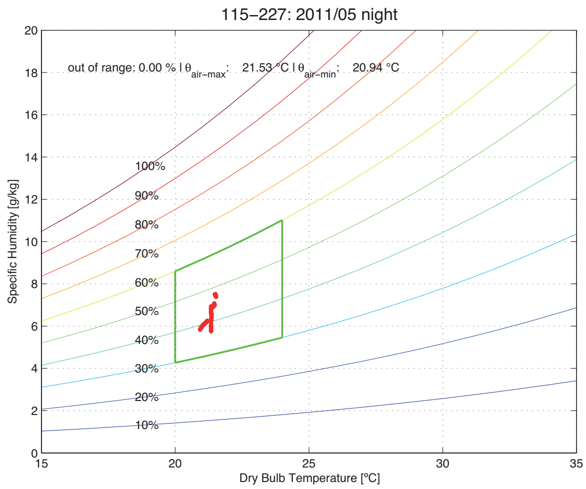


Fig. 117 B - T1-225-Night-May

Figures 106 -116 show the studio values for units 118 and 225. They illustrate that the temperature of the units remain 80% to 90% within the comfort zone. The values may confirm East- West the building position may help reduce solar heat gains in the building. In the evaluation of the day and night the results show no temperature differences through the analysis.

4.1.4. Predicted Mean Vote and Predicted Percentage of Dissatisfied

The predicted Mean Vote determines the expressed values of comfort levels in the human body. The satisfaction levels are affected by various factors such as clothing, and metabolic rate and temperature that are then depended on the activit of the students while in their dormitorie units. In the case of Kandlgasse student housing, there were some assumptions made in terms of the daily and nightly activities of the students. The data collected for the PMV values are divided in time slots from 8:00 to 20:00 morning activities or no activity while students are in class during the morning period and 20:00 to 8:00 night for sleeping or studying. In order to get some comparative results it is necessary to get a percentage of satisfaction of the indoor environment of the residents. The PPD provides a percentage of the PMV values to get comparative results. The values of assessment for the PMV are from -0.5 to 0.5 that determines the range of comfort. According to ISO 7730 this range predicts the satisfaction below 10% that defines acceptable indoor climate conditions

Overall Comparison

figures 118 and 119 show the predicted mean vote for the sleeping room units. It is important note As noted in building B one-bedroom/ studios where living and sleeping take place in one room as a results the comparative is not at equally comparable.

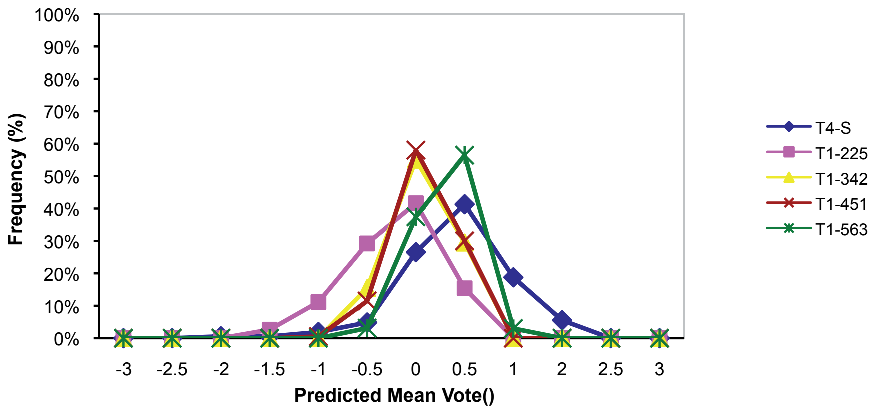


Fig. 118 A + B-S -All Units-Whole Period

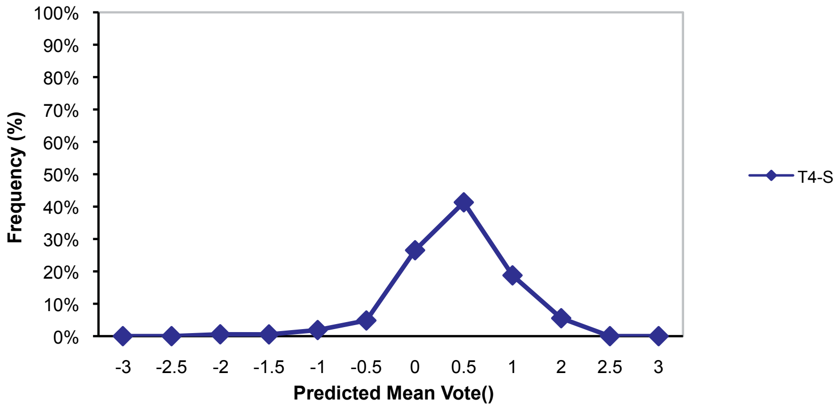


Fig. 119 A - T4-671-S-North Facing - Whole Period

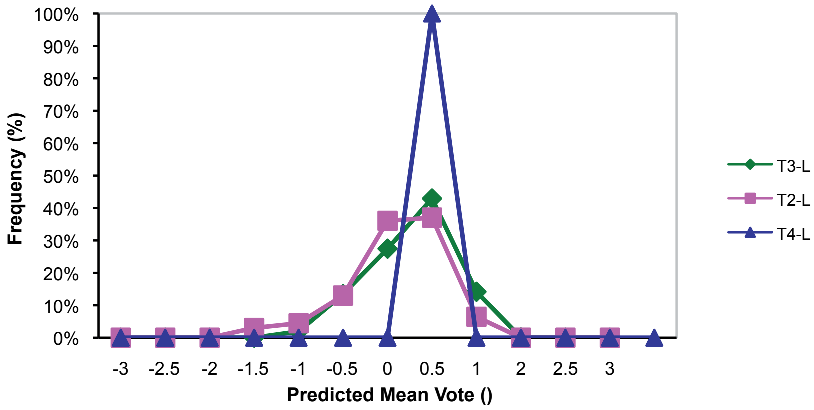


Fig. 120 A - L - Whole Period

In figure 119 the predicted mean vote stay well between -0.5 and 0.5 indicating a neutral range in the thermal comfort levels and levels of satsifaction. These results are comperable with the results showned by the students questionnaires.

In figure 119 the bedroom facing North in of building A shows clearly that it maintains a predicted mean at a comfort level. This may confirm that the units facing south have a slightly higher PMV.

In figure 120 unit 671 show predicted mean values higher than the rest of the apartments in building B. The air temperature in thermal comfort affects the human's body physical and mental condition. When the PMV is in a range of 1 the people in the room are aware and start feeling discomfort.

The result can again be reinforced from our previous findings that the high temperatures in these units can increase the discomfort levels. In addition, the values could be higher because of the possible unit orientation and user behavior.

4.1.5. Predicted Percentage of Dissatisfied

Table 17 specify PPD and PMV calculations values indicating the percentage of thermal comfort on each unit evaluated. Building B shows not significant differences between the living room units and the one bedroom/studio. In the month of May the overall percentages of dissatisfied are high in all the units and later dropped in the month of May. The best values are in units 451, 223, 118 and 112. In comparison with building A and building B, the units in building B show lower values that might contribute to the fact that the building have normal temperature thru the study period while building A shows in the readings show a higher rate of temperature fluctuation.

Tab.17 Predicted percentage of dissatisfied (%)

	Building A				
Month	**671LR**	**671 SR**	**112LR**	**223 LR**	**118LR**
February	11.5	8.4	7.7	7.2	6.2
March	5.7	7.7	8.6	6.4	5.7
April	7.3	5.7	6.6	6.9	8.2
May	19.1	24.2	21.1	42.6	21.1
whole Period	**11.2**	**10.5**	**9.4**	**11.2**	**8.9**
Average	**11.0**	**11.3**	**10.7**	**14.9**	**10.0**

	Building B			
Month	**225**	**342**	**451**	**563**
February	6	5.9	5.9	6.5
March	6.2	5.7	5.9	6.1
April	12.7	6.8	6.2	5.5
May	53.1	19.3	18.2	5.6
whole Period	**13.3**	**7.3**	**6.5**	**7.3**
Average	**18.3**	**9**	**8.5**	**6.2**

PPD show peoples dissatisfied percentage should not be lower than 5% (OeNORM, 2006), In the intent to get the % of for PPD sets of parameter were obtianed the values according to the Clo, day or night acitivities, velocity,relative humidty that will adentify the comfort conditions. The Clo values were also defined by the assumed daily activities of the residents.

4.1.6. Carbon Dioxide Concentration

Overall Comparison

The following graphs show the communlative frequency of CO_2 in units 671 and 112 where measurements were taken. Note that carbon dioxide concentration measurements were only done in units located in building A.

Building A

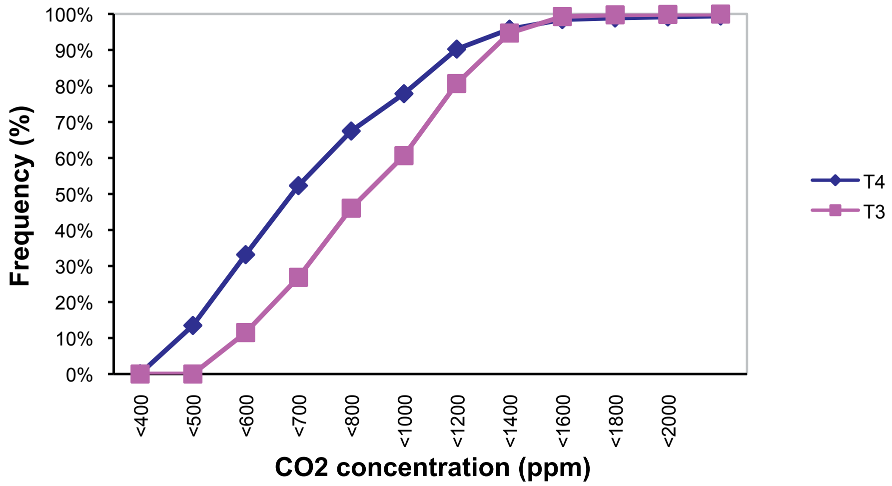


Fig. 121 A -T4 -T3-L-Whole Period

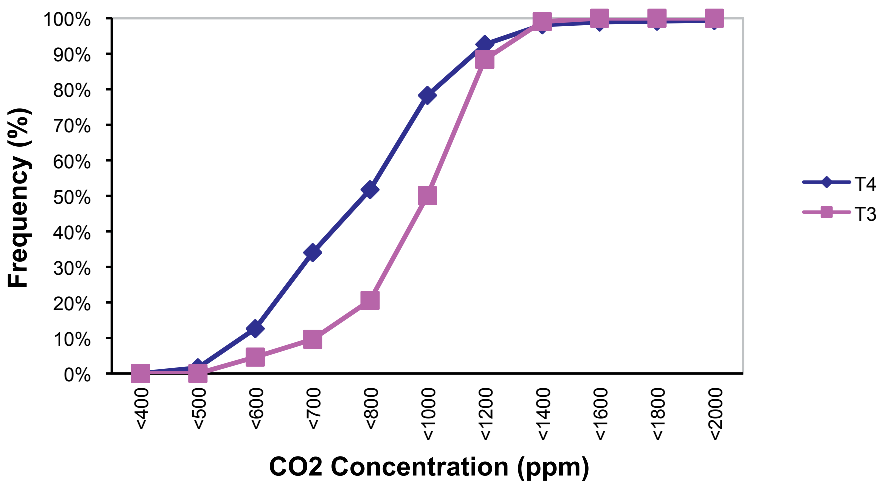


Fig. 122 A -T4-T3-L-Feb

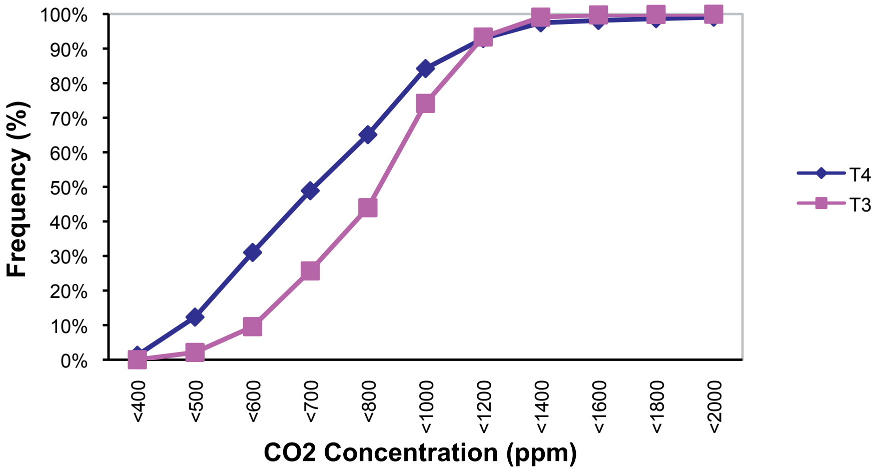


Fig. 123 A - T4-T3-L- Mar

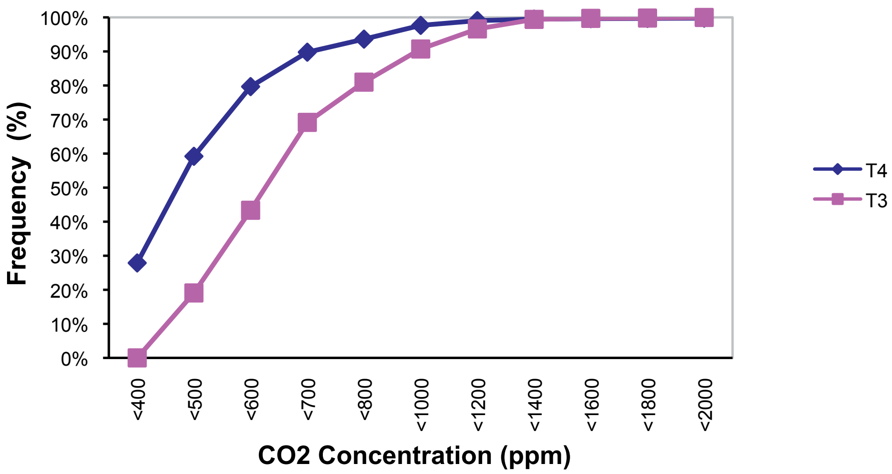


Fig. 124 A - T4-T3-L-Apr

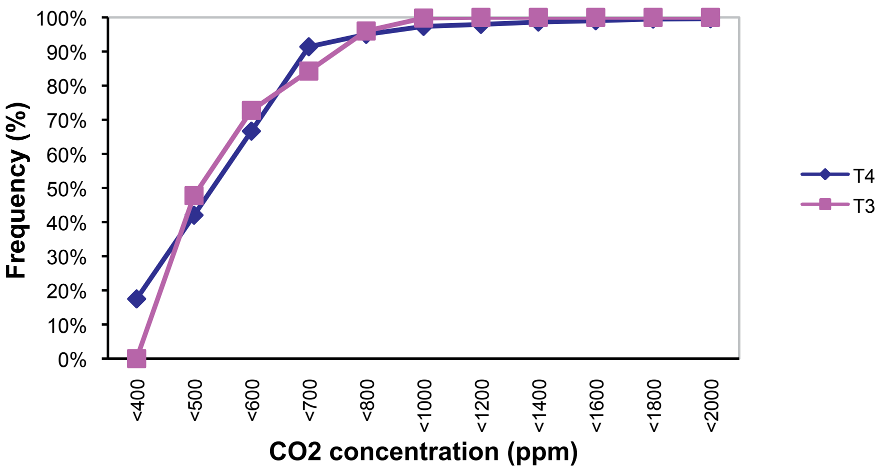


*Fig. 125 A -T4-T3-L-*May

The CO_2 concentration levels were only taken in the large apartments. The Carbon dioxide values shown in the cumulative distribution graphs in figures 120 and 124 indicate that the CO_2 values for the whole evaluation period are in a range between 700 to 1400 ppm. However in the months of April and May the CO_2 values were lower. It is important to note that, during the evaluation period, in the months of April and May students opened their apartments windows when temperatures were in various days “summer” like temperatures. As a result the carbon dioxide values could have dropped while there was external airflow coming into the building.

The temperature readings for these two apartments showed high temperatures not only in the warmer periods of April and May but also in the month of February; as a result it is possible to also consider that even though the temperature levels were high, the CO_2 levels were maintained in a range of 50 to 65% when the specified threshold is 1000ppm.

In comparison with the two building units #671 and unit #112 the values indicate that unit #112 a three-bedroom apartment had higher CO_2 concentration levels than the apartment # 671 when considering apartment size in the evaluation results.

4.2. User Evaluation

In the user evaluation the students were provided with a questionnaire to complete. However, while a large amount of students did not submit their responses an evaluation questionnaire done by the OeDA was also reviewed to reach possible conclusions.

4.2.1 Questionnaire by Residents

The questionnaires were submitted to 65 residents, including the residents where the measuring devices were placed. The resident’s questionnaire constituted a series of questions related to their comfort levels, temperature, ventilation and related questions such as satisfaction issues with the building’s performance. Considering the low amount of responses by the residents there results have a low percentage of value in the overall finding. However, in addition to the questionnaire submitted to the residents for this analysis, a previous questionnaire was done by the OeAD housing office Vienna for the duration of the winter-summer of 2010, this study was also used as a baseline for possible conclusions about user satisfaction evaluations at Kandlgasse. In order to generate a broad understanding the current building performance there were a series of informal interviews done to the building’s personnel who were aware of the overall building conditions and administration. The questionnaires were written in English and were given to the students on April 25th 2011.

Question 4

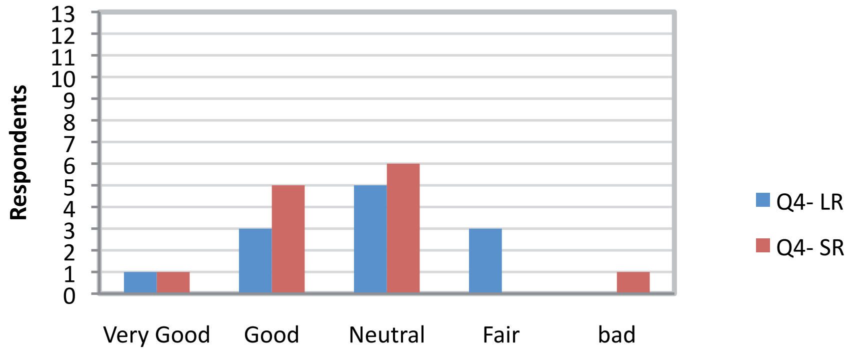


Fig. 126 Question 4- indoor air quality

The questionnaire had sections with questions related to ventilation, temperature and lighting.

In the first set of questions were related to satisfaction in the ventilation system and air quality in their apartments.

Figures 126 question 4 and Figure 127 question 5 show that air quality is acceptable but in terms of air humidity 40% of residents find the air too dry. In passive house standards required that in air tight building to have values of n50<0,6 h-1. “In a passive house dormitory daily values n50 are 0.6 h-1 therefore the pressure differential of 50 pa 60% replacement of air volume in a vacuum suction procedure, by resulting in higher heat consumption” (Treberspurg, Smutny 2009). Nevertheless, the mayority of residents are satisfied.

Question 5

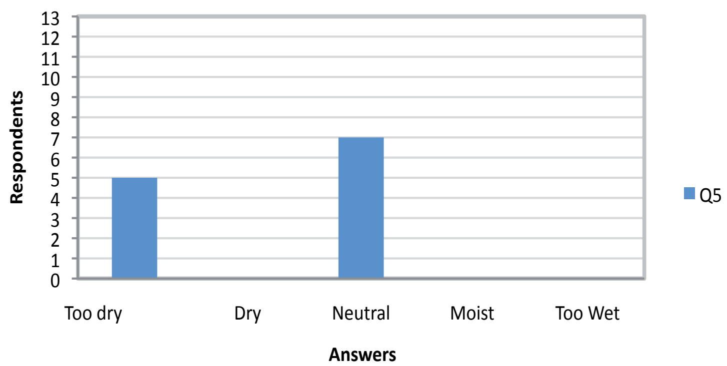


Fig. 127 Question 5- Indoor air humidity

Question 6

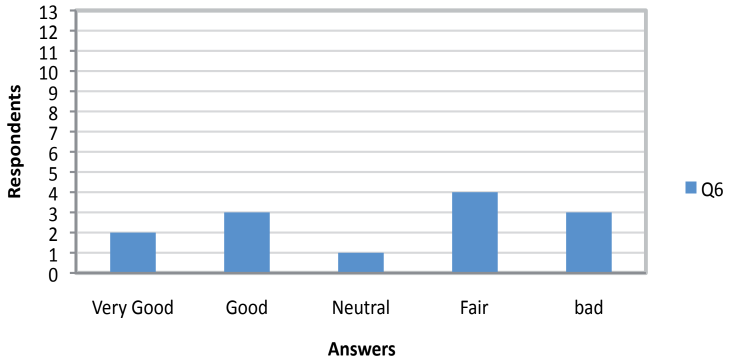


Fig. 128 Question 6- Air circulation

Question 7

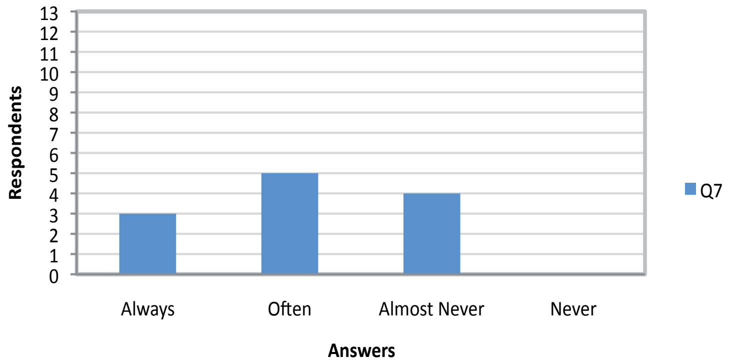


Fig. 129 Question 7- Air smells

In student dormitories the building temperature was relatively in a range of 21°C - 24°C. In questions 8 thru 10 students were asked about behavior in relation to indoor and outdoor temperatures. In the majority of the responses 7 out of 12 students found the current room temperature neutral and the other's somewhere in between rather hot or rather cold.

In addition, when asking students about the radiator 80% of the students responded that they used the radiator always or sometimes in their units. In the evaluation responses 80% of females ages of 20 to 24 gave these responses. This suggests that females preferred higher thermal temperatures than male residents. The WBGT also suggests that males prefer a temperature of 22°C while 25°C for females. They are tending to be significantly higher.

Question 8

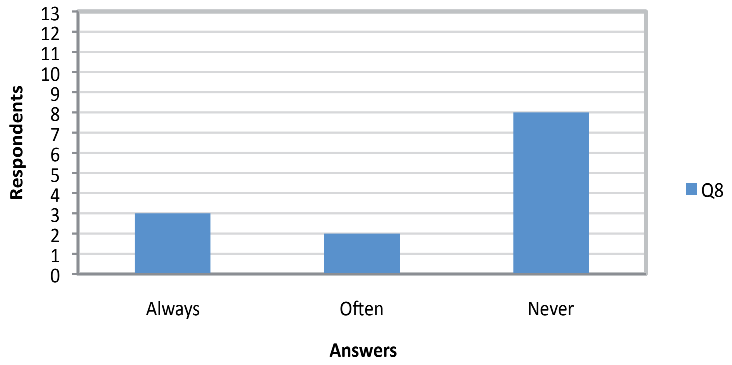


Fig. 130 Question 8- Windows

Question 9

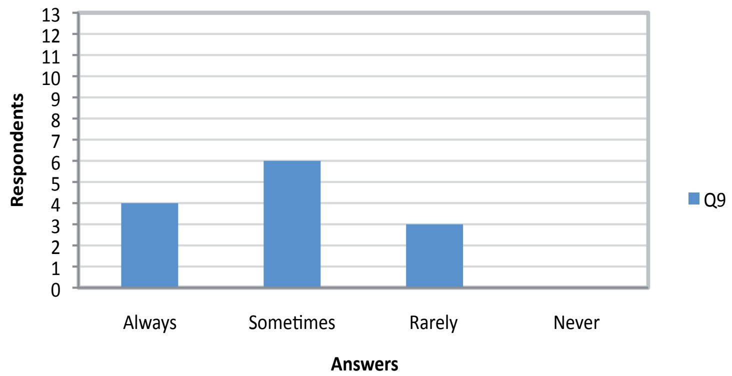


Fig. 131 Question 9- Radiator/space heater in the unit

Question 10

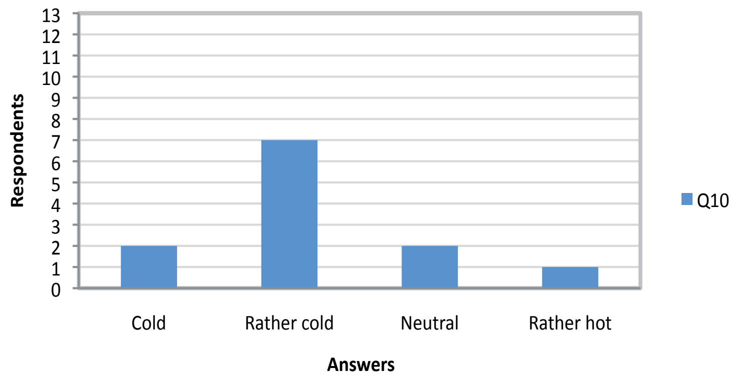


Fig. 132 Question 10- current temperature

Question 11

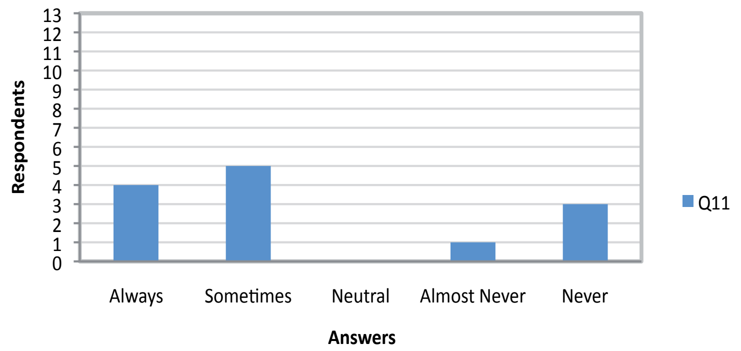


Fig. 133 Question 11- Natural light values in the unit

In figure 133 question 11 students were asked about lighting factors in the units. Most of the students felt satisfied with the amount of natural light coming into the building. In addition students in the both building A and B used the window blinds in winter and summer period. While the majority answer that they used the lights always or sometimes, they also use the blinds often or sometimes. See figure 130.

Question 12

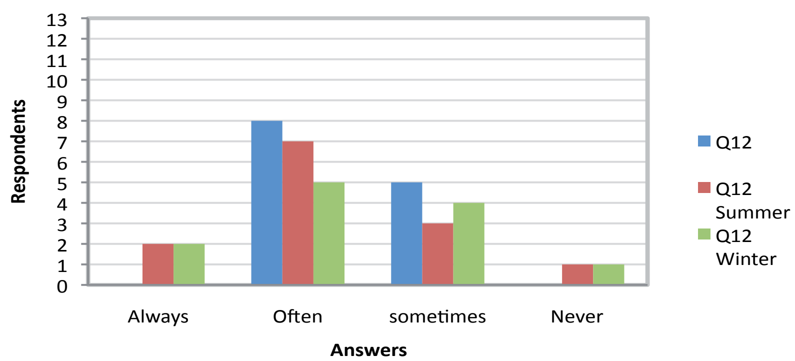


Fig. 134 Question 12- use of blinds thru the summer and winter period

Student were asked if they felt the need to use their blinds and in which period. The responses show that the majority used the blinds at all times. Considering that light factors are different in each building. It is clear that students living in units facing South use the blinds in the summer time to avoid glare or heat coming into the units. In the evalutions students from units located in building B felt that the limited amount of natural coming into the building forced them to turn on lights during the day. However, in site observations students in these units had 70% of the time their window blinds down.

Overall

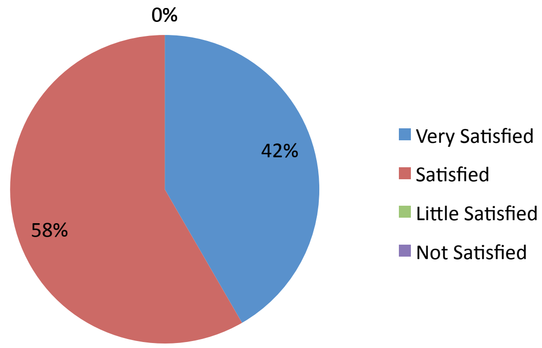


Fig. 135 Overall- building satisfaction

In the overall conclusions of how satisfied they are living in Kandlgasse30 the results show that they are either satisfied living in this student housing project.

Other comments by students

Students had the opportunity to make comments or voice concerns about possible building improvements in Kandlgasse. Only 20% of the students provided comments, therefore responses are not largely comparable with the majority of residents.

1. Most resident find that the cooker hoods (with grease filters) do not work well and the smell
2. of food remains in the room for a long period of time.
3. The amount of natural light coming into the kitchen area in both buildings A and B is very poor and they find in some cases to turn on the artificial lighting during the day.
4. Students complain that room temperature in the bathroom is low.
5. There is glare issues in some of the units, here is a need to maintain the blinds closed durinng the daytime in the summer period.

4.2.2. OEAD- Fragebogenauswertung zum Thema Passivhaus

An evaluation questionnaire in the topic of Passive House was done by the OEAD in the winter 2009 and summer 2010. In this questionnaire a series of questions related to air, temperature, living quality as well as maintenance and sound distribution. This questionnaire was done with the collaboration of the Universitaet fuer Bodenkultur Wien.

Within this comparative analysis of three student housing projects in Vienna including kandlgasse 30 in a summary the results indicated the following findings:

- 62% responded that they were satisfied with the air quality of the room and felt no great need to open the windows to get it.
- During the summer period students keep the windows open three to four times per week and 27% of the students only open the window if the air was too dry.
- In some cases student open the window because there was not enough air circulation after cooking.
- In Kandlgasse students felt it was too hot in their units during the summer time.
- There was no way to separate waste.
- In term of noise students in kandlgasse felt that sound insulation was poor and they could hear other residents’ noise from their rooms.

4.2.3. Interviews

In the study of user comfort evaluation a diverse community of residence as well as students were interviewed get an evaluation of the interaction of the diverse user in the building and therefore be able to evaluate the building based on people’s needs and activities.

4.2.3.1. Interviews to Employees

In Vienna’s student housing, the students receive a cleaning service to their unit weekly as well as regular maintenance of the building. There were 4 interviewed personnel who answered verbal questions in relation to their experience working in a passive house building as well as their satisfaction with the building’s performance.

Cleaning personal

- In their time working in the Kandlgasse project they found to have minor problems in general with the building.
- Based on their experience working in past year at the Molkereistrasse passive house student housing they felt that the ventilation system in kandlgasse was much better. The three employees found the air flow in Molkereistrasse was too dry.
- When working, they complained that for the 6th and 7th floors in the building facing south the inside temperature in the spring or summer was extremely high some where between 28°C to 35°C

Maintenance Personal

- The maintenance personal is currently working in both the Kandlgasse student housing and the Sechshauser Strasse Passive house student housing.
- The interviewed personal is satisfied with the Kandlgasse project, they find minor issues in the maintenance but yet normal for any building this type.
- One comparison was made with the Scheshauserstrasse passive house project where the building had various issues related with the ventilation system as well as the window system.
- They are very satisfied with the building for the past few years.
- In terms of the personal opinion about user interaction with the building the following points were mentioned:
  - The residents sometimes do not pay much attention about living in a passive house building.
  - Many residents find in the winter season that their unit is too cold while receiving phone calls by the residents that the heating system was not working in the winter season
  - They find that in various occasions students are using the radiators and also leaving the windows open.

After doing an evaluation of the responses the findings show that 95% of the students are living in a passive house building have little knowledge about living in a passive house building. The question of what kinds of people are interested in living in a passive house building has to be raised. Are students attracted to live here because this is an energy efficient building?. In the questionnaire evaluations students were asked if they review the student manual provided to them when they moved into the unit. 50% of the students responded yes. In the manual there is a simple explanation of how to use the building and how the building mechanical systems works. In terms of behavior, most students have very little knowledge and how the passive house building operates.

4.3. Energy

In the Kandlgasse project energy consumption costs are heating and the electrity demand. Currently, the OeDA does not have a complete evaluation of the building total energy consumption costs and values. There is research currently being done to optain these values. Therefore some assumptions were made to get values for the current energy demand of the building in this evaluation.Table 18. List of the kandlgasse service provider. The intent of the building owners had the interest of using as much renewable energy in the building coming from different sectors to reduce the amount of CO_2 production.

Tab.18 Service providers- Heating and Electricity

Sector	Service
Fernwaerme by WienEnergie	Warm water/Heating
Oekostrom	Green electricity
Photovoltaic	electricity

4.3.1. Fernwaerme (district heating)

The building heating demand is 15 kWh/(m^2a) by definition of PHPP.
Wien Energie provides the district heating to the building with an heat exchanger to provide warm water and heating for the building's radiators for all rooms in the building. The energy of Fernwaerme distributed through a piping system around the city. This energy is produced by cogeneration of heat and power in the waste power plant method results in the reduction of CO_2 emissions that contribues to the Passive house concept of green energy.
Building net usable are m^2 = 3,149
HWB kWh/m^2a = 15
Overall HWB (expected) kWh/ Year = 47,235
N= 0.8

$$15x\ 3,149= 47,235 \times N = 60.000 \text{ kWh}$$

This result is an estimate of the total kWh for the building per year.
Data or measurements for the warm water and district heating used in the building could not be obtained for analysis. Presently, a research in the current building heating demand is being done by Schöberl & Pöll GmbH who were in charge of the building physics.

4.3.2. Electricity

The figure 136 shows in blue the total electricity used - kWh/per month for the year 2010. However the months of October and December are not included. In red is the total amount of electrity produced by the photovoltaics that is redistributed into Vienna's power grid. The results show that the energy used stays below 7.500 kWh in the winter period but in the summer time drops into the low 5000 kWh. While taking into account that in the summer the heat exchange is turned off and more natural light coming into the building the overall electricity costs are lower.

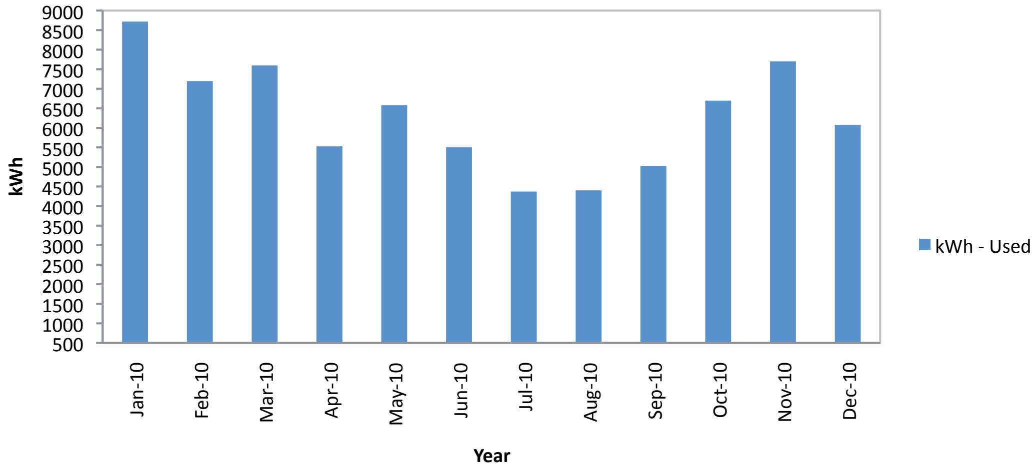


Fig. 136 Electricity Consumption year 2010 at Kandlgasse 30- Oekostrom bills

Table 19. provides the calculated values per/month of energy used and cost for electricity only for the year 2010 this values were calcuated base on the energy bills provided by OeDA from their montly energy bills.

Tab.19 Oekostrom- Green energy- bills for year 2010

	Energy cost/€	**kWh - Used**
Total	13.735,83	75.396,00

4.3.2.1 Photovoltaics

The photovoltaic system values of energy production shown in table 20 show that the photovoltaic system energy productuon varies thru the year, but the expected values show to be consistant but in the month of March energy production was very low. This can be attribute to possible winter snow during this period.

Tab.20 kWh produced by Photovoltaics- Sept09 - March10

Photovoltaic	Total kWh
Calculated Energy	7,305.00 kWh
Actual Energy	5,749.700 kWh

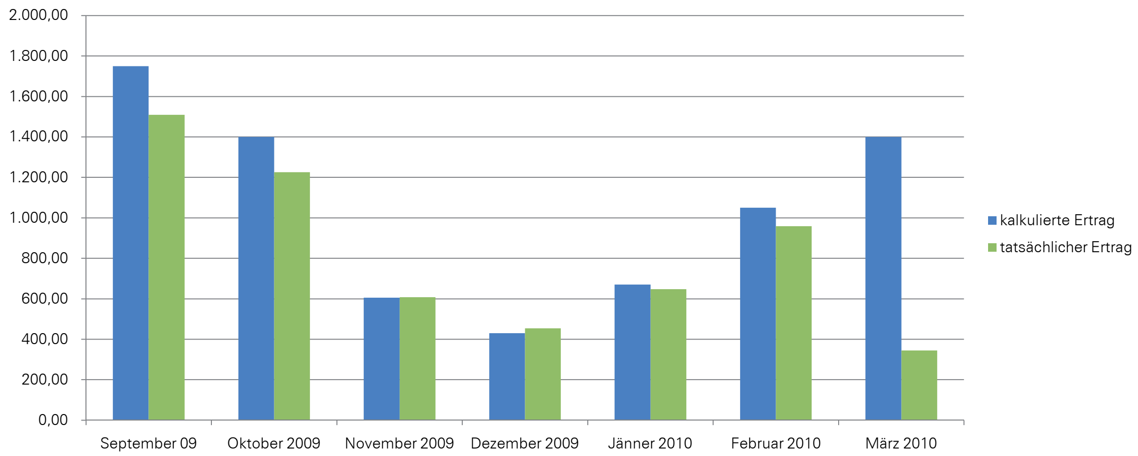


Fig. 137 kWh Produced by the Photovoltaic 2009-10 at Kandlgasse 30-(OeDA,2010)

When looking at table 21 the estimated electricity consumption of 80.305kwh correlates to the actual electricity consumption of 75.396 kwh. The photovoltaics system produced less kwh than calculated. However, the estimated values of kWh/ year of electrical power consumption both with Oekostrom and Photovoltais has approximate the expected electricity consumption of the building per year.

Tab.21 Eletricity consumption estimation- (OeDA,2010)

Net usable area m²	Total kWh/Year (Estimated)	Photovoltaics kWh (Calculated)
3.104 m²	75.000,00 kWh	5,749.700 kWh
80,749kWh* (estimated values, not enough data to support these values)		

5. CONCLUSIONS

5.1 Main Contribution

The overall aim of the study was to perform an analysis on energy building consumption and that the evaluation of the user comfort satisfaction in a passive house building. The results indicate that the Kandlgasse building's performance meets the expectation concerning indoor environment conditions. However, the temperature evaluations have shown that the building's design and orientation has affected the building heat loads that have resulted in high temperature in most of the 6th and 7th floor units. As a result the ventilation system has to work at higher rate to maintain lower temperature in these apartments. A more detailed analysis should be executed to find possible simple methods to lower the heat gains on this side of the building. In consideration that this is a multi-story apartment and the mechanical systems work accordingly to their performance standards, no major maintenance issues have raised since the building started to operate. After the analysis and the questionnaires a large amount of student felt that the room temperatures in the wintertime were too cold. For instance, unit 671 in the winter period had temperatures ranging from 25°C to 27C° and later in the month of May the indoor room temperature dropped drastically to 22°C to 20°C. This significant change in temperature comes from the users interaction in this case opening the windows although one would expect rising temperatures in the unit during an unusually warm May of 2011. In this case, is relevant to say that high temperatures in March and April were caused by the use of the apartment radiator units and not to solar heat gains. As a passive house building the thermal conditions a considered adequate. However, in some cases the results show the relative humidty values especially in the winter period reach relative dry that could be a result of the ventilation system. 40% of the students have some level of dissatisfaction with the room temperatures of the apartment during the winter time are too low.

The residents and the working staff are satisfied with the current building's performance and internal conditions of the building. Furthermore, possible incentive methods for students can be developed to get residents informed about best user practices of living in a passive house. It is obvious that in a multi-story building the resident population varies constantly and has a high rate of turnover yet the student's behavior affects in a large scale the building's performance.

In terms of the building design one of the biggest advantages was the separation of the building in two wings. The layout allowed for good use of the infill site as well as the access of natural light to different areas around the perimeter of the buildings. This provided the opportunity to reduce the need of artificial light in the corridor and the amount of luminance in the building. However, the building facing East seems to have more issues with natural light coming into the unit specially the kitchen area and there were indications that the students had the need to turn on the lights during the day to get wanted level of illuminace in the room.

In conclusion, energy consumption, as well as user interaction are clear inter-related factors in the performance of a passive multi-story building. However, factors such as natural light quality, building design and methods can become an determent in reducing the need in this case electricity as well as in how well people feel in the building and as result generating positive living behavior.

5.2. Future research

For future analysis it will be important to do an extended data collection for a whole year or more. The analysis could gather actual daily and monthly readings of energy usage and the building system performance through each season which is important for analysis of a passive house project.

In addition the current building analysis CO_2 data collectors were placed only in two units of building A. Therefore, the use of multiple CO_2 sensors in various building locations will gather a larger ration of measurements for each building and unit type. In further research, it would be of interest to perform a detailed study of the building construction and design typologies that would work best in multi-story Passive house design while considering building mass as a conservation method for green building construction.

As the intent of building a passive house project is to reduce energy consumption and reduce dependency on fossil fuels the possible evaluation of multiple methods of green building construction can provide new and improved methods of future building construction.

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6.2. Tables

6.3. Figures

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Above all I want to thank my parents and friends specially those who helped me through my studies and kept me motivated to reach this goal. Special thanks to Dipl-Ing. Marc Remshardt.

7. APPENDIX

7.1. Hobo Locations

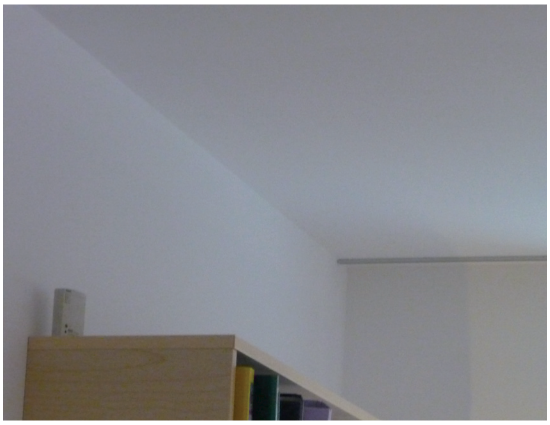

Fig. 138 Hobo- Bedroom

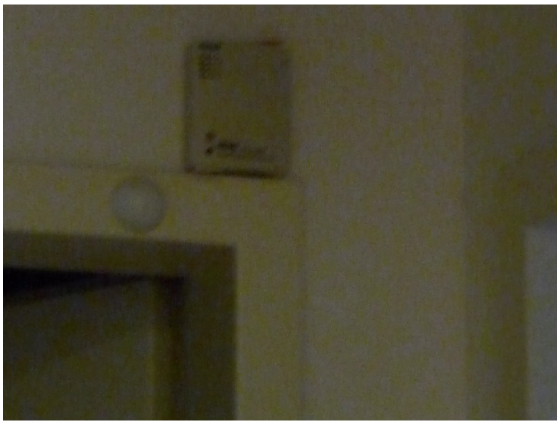

Fig. 139 Hobo- Living room

Fig. 140 Hobo- CO2- Living room

Fig. 141 Hobo- Livingroom

7.2. Psychometric charts

A-T2-223

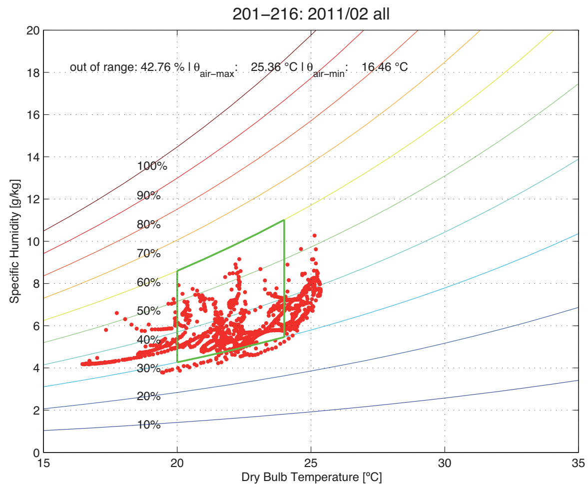

Fig. 142 A - T2-223-L-Whole Period Feb

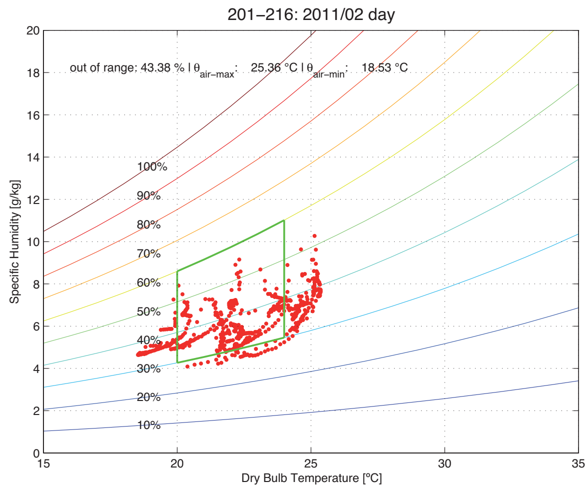

Fig. 143 A - T2-223-L- Day-Feb

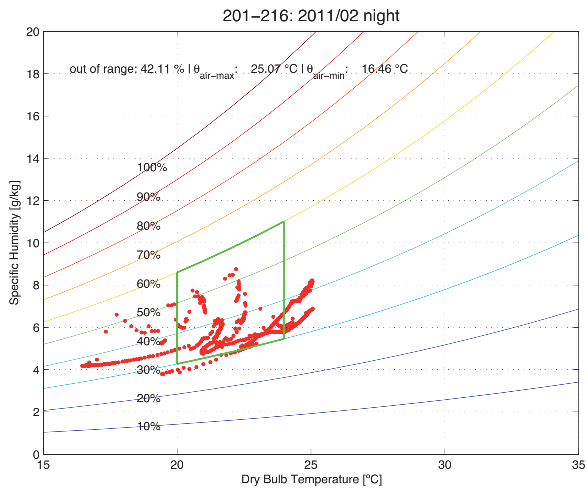

Fig. 144 A - T2-223-L- Night-Feb

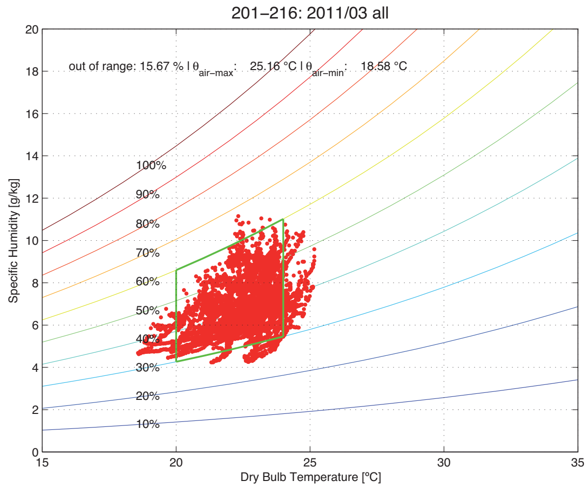

Fig. 145 A - T2-223-L-Whole Period Mar

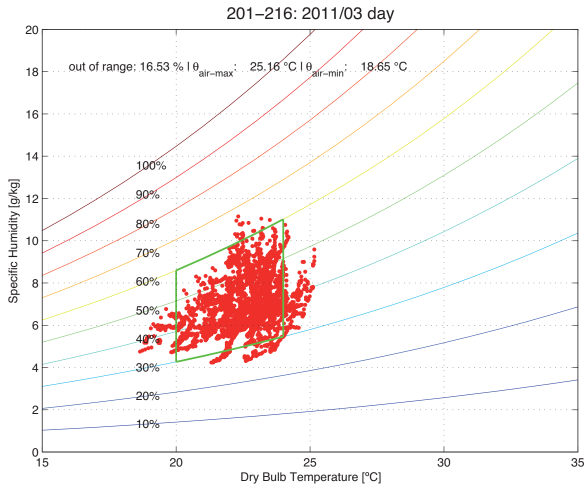

Fig. 146 A - T2-223-L-Day-Mar

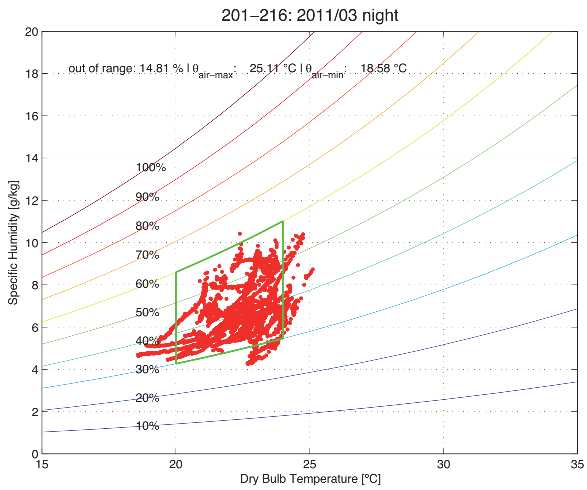

Fig. 147 A - T2-223-L-Night-Mar

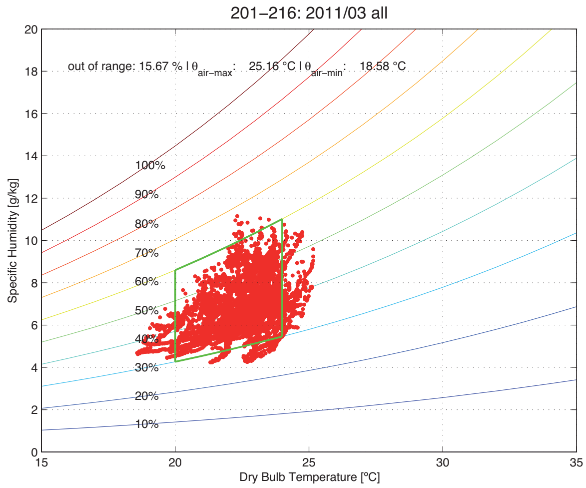

Fig. 148 A - T2-223-L-Whole Period Apr

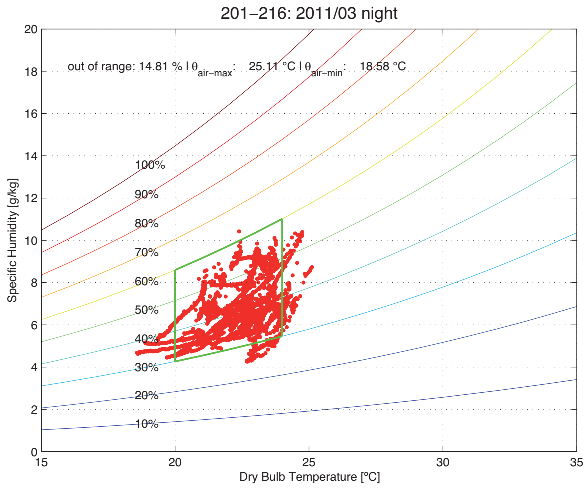

Fig. 149 A - T2-223-L-Day-Apr

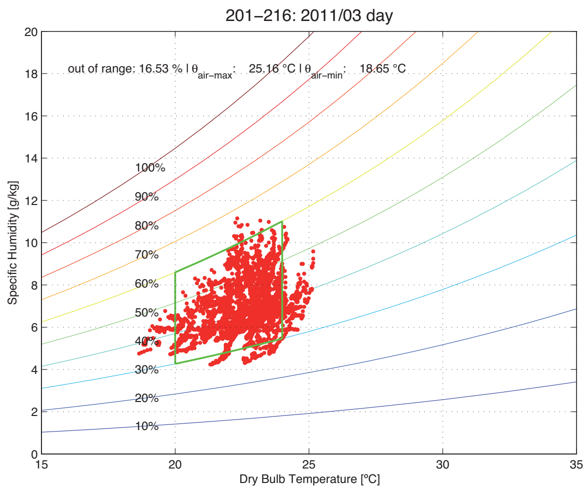

Fig. 150 A - T2-223-L-Night-Apr

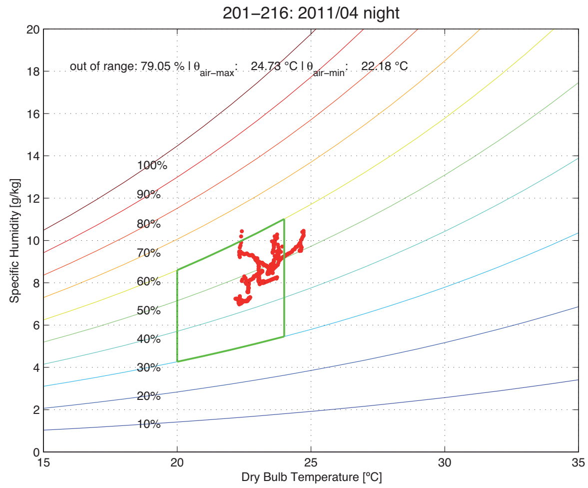

Fig.151 A - T2-223-L-Whole Period-May

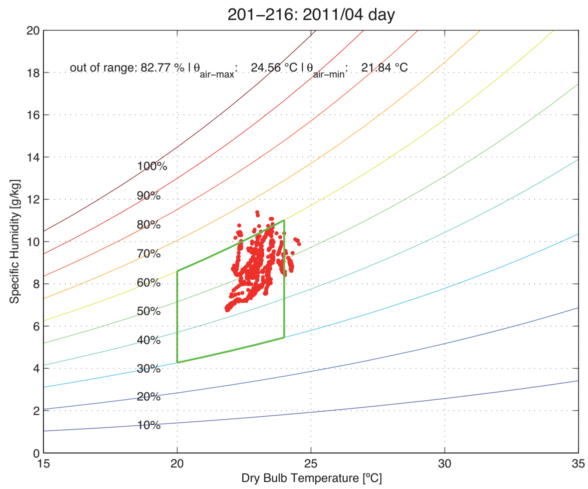

Fig.152 A - T2-223-L-Day-May

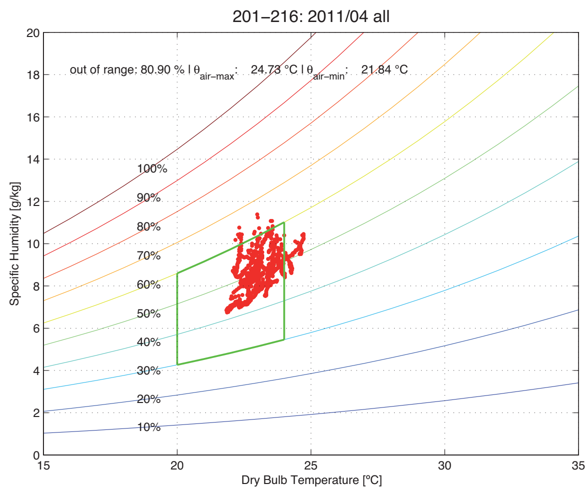

Fig.153 A - T2-223-L-Night-May

B - T1-342

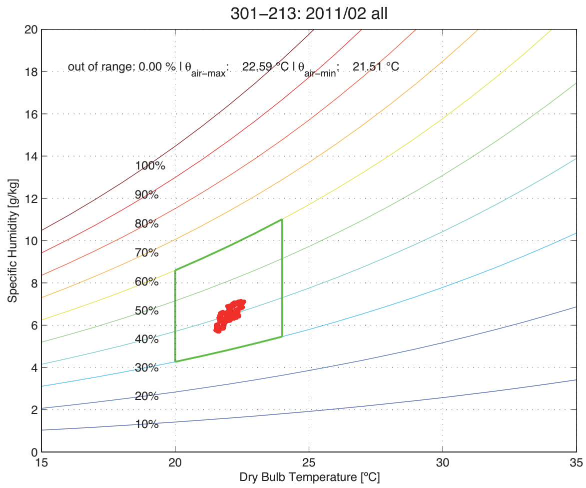

Fig. 154 B - T1-342-Whole Period-Feb

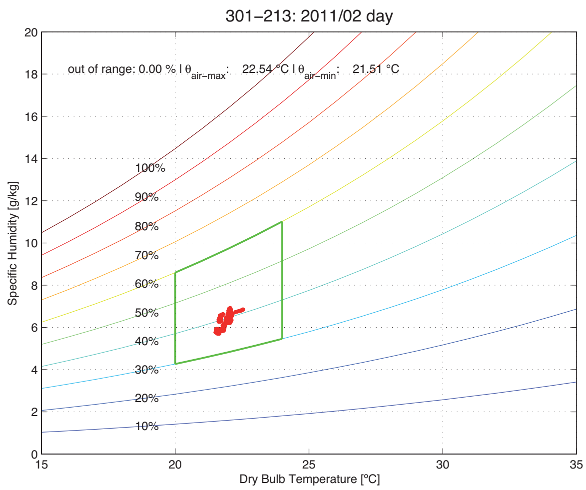

Fig. 155 B - T1-342-Day-Feb

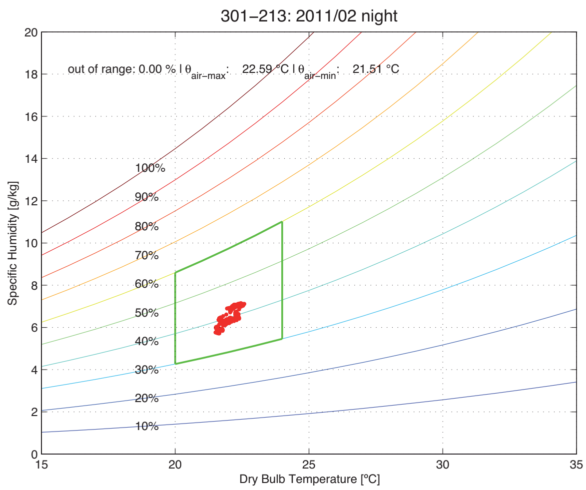

Fig. 156 B - T1-342-Night-Feb

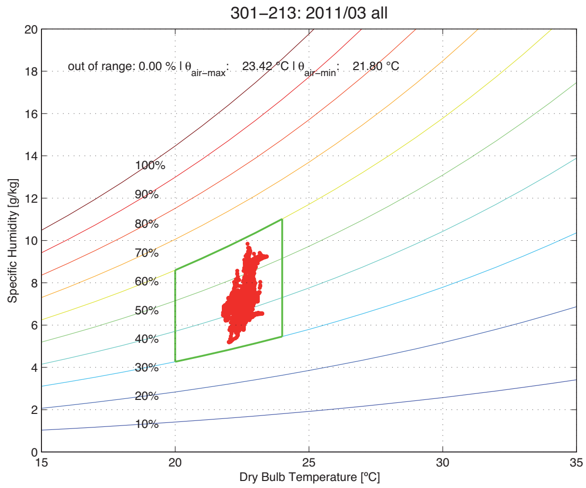

Fig. 157 B - T1-342--Whole Period- Mar

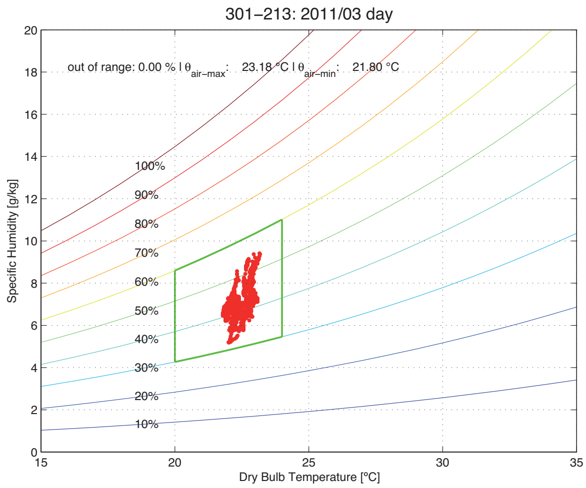

Fig. 158 B - T1-342-Day-Mar

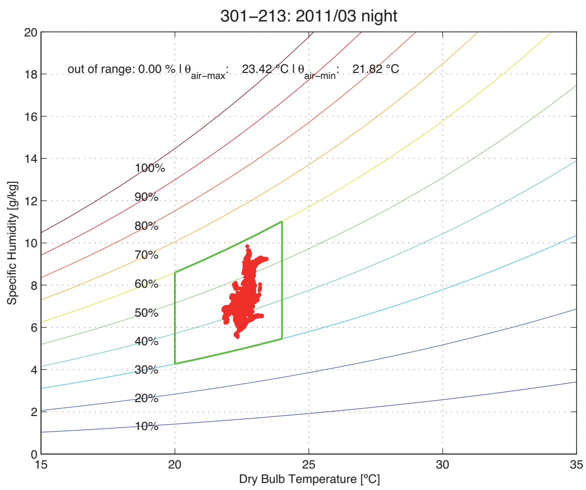

Fig. 159 B - T1-342-Night-Mar

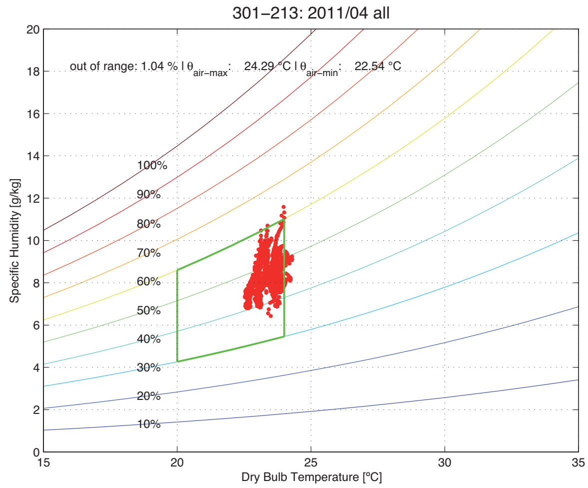

Fig. 160 B - T1-342--Whole Period- Apr

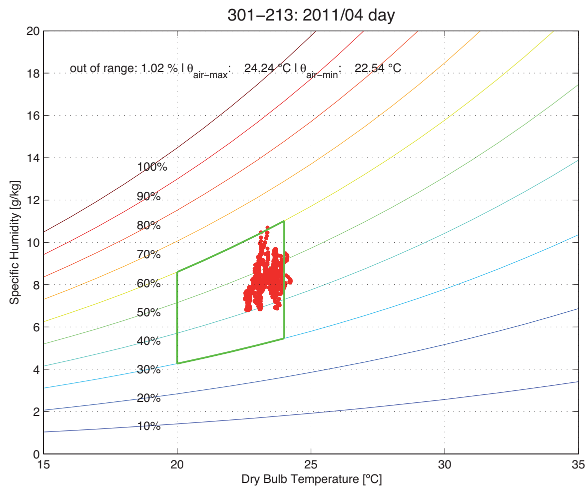

Fig. 161 B - T1-342-Day-Apr

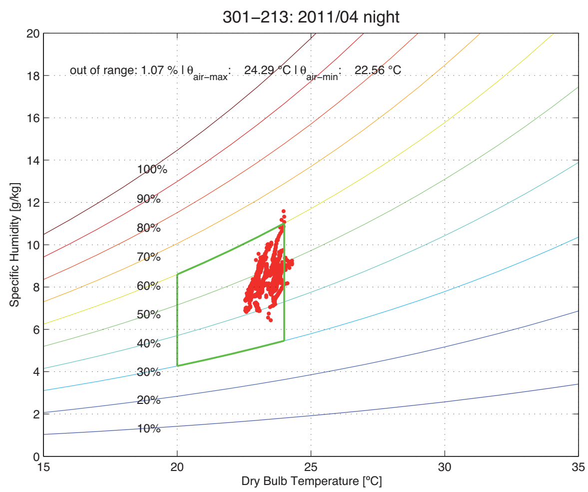

Fig. 162 B - T1-342-Night-Apr

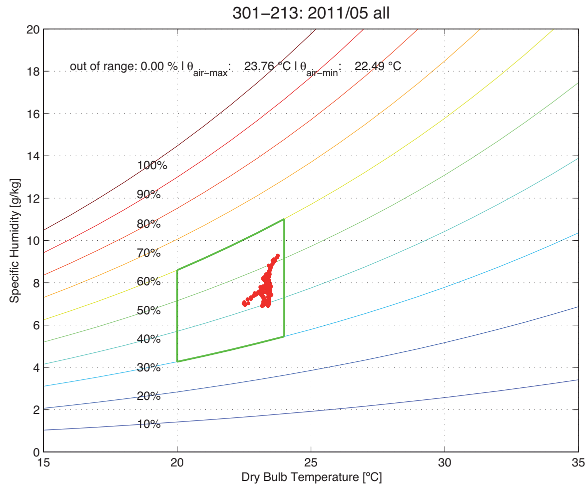

Fig. 163 B - T1-342--Whole Period- May

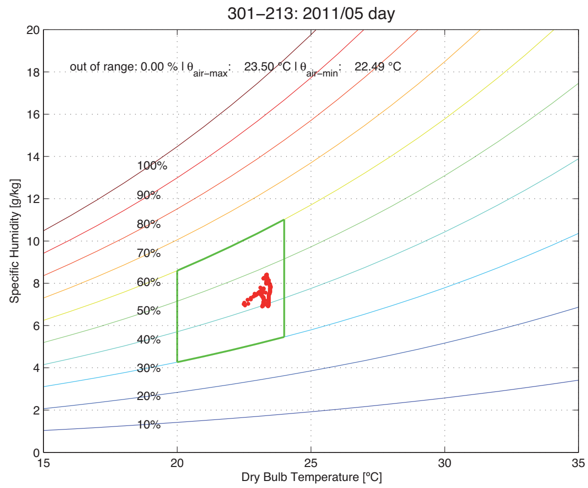

Fig. 164 B - T1-342-Day-May

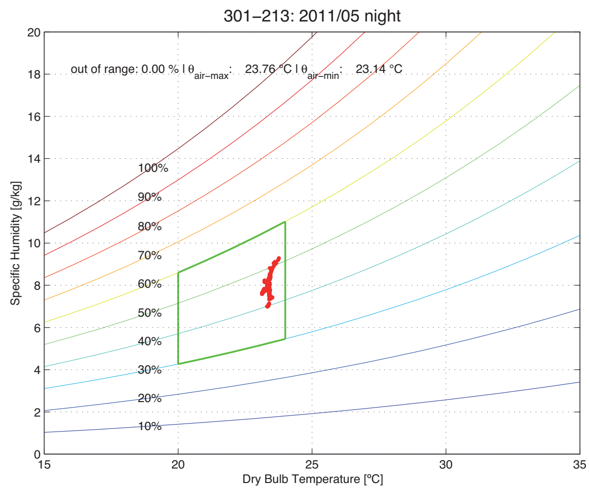

Fig. 165 B - T1-342-Night-May

B - T1-451

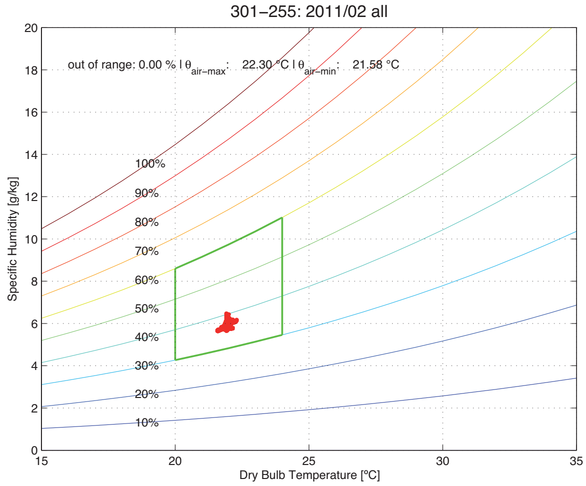

Fig. 166 B - T1-451--Whole Period- Feb

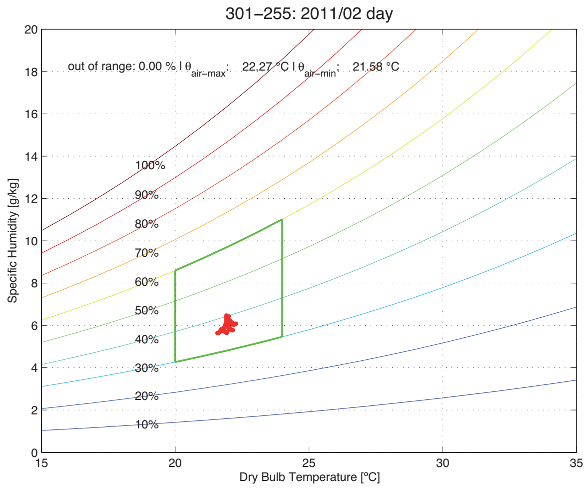

Fig. 167 B - T1-451-Day-Feb

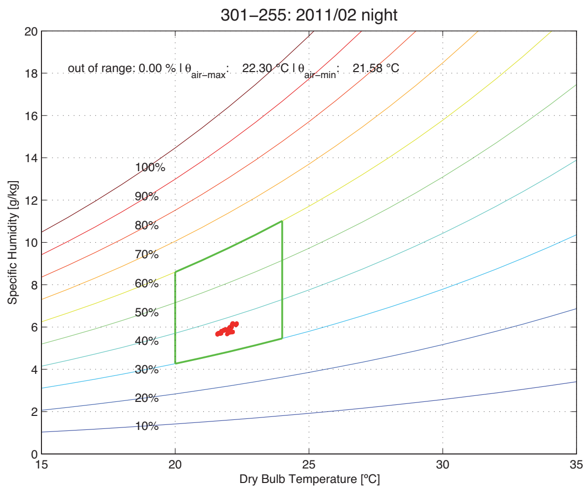

Fig. 168 B - T1-451-Night-Feb

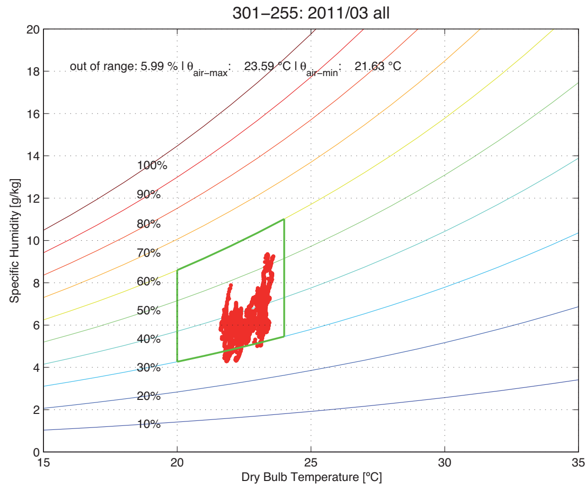

Fig. 169 B - T1-451--Whole Period- Mar

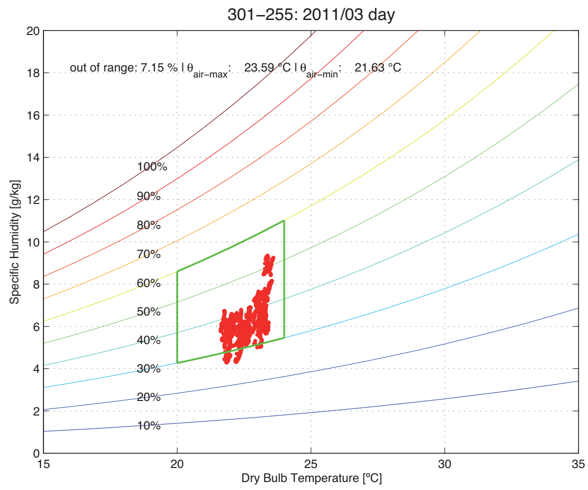

Fig. 170 B - T1-451-Day-Mar

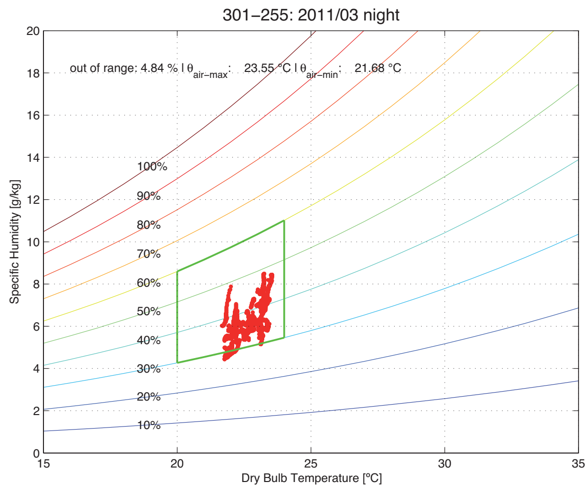

Fig. 171 B - T1-451-Night-Mar

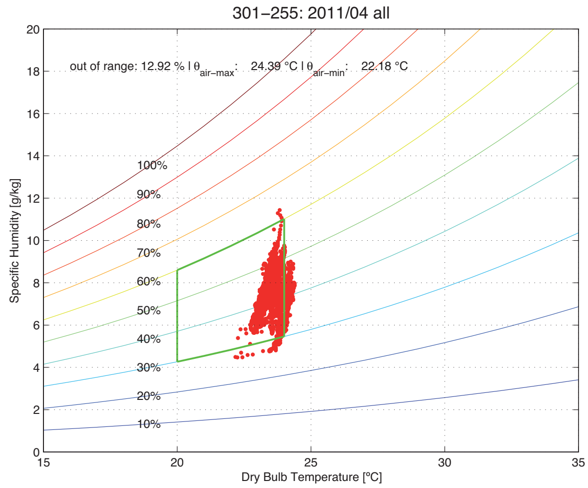

Fig. 172 B - T1-451--Whole Period- Apr

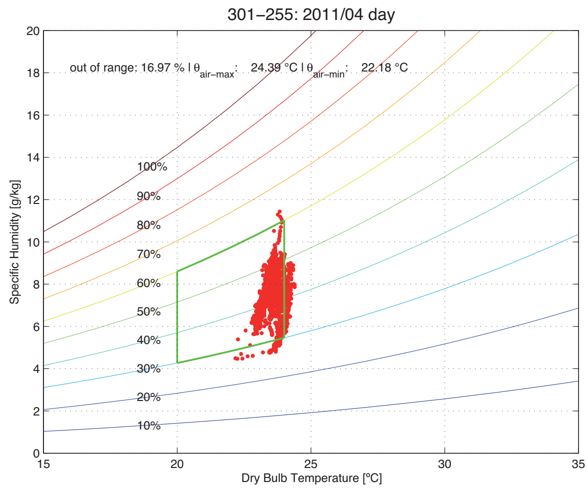

Fig. 173 B - T1-451-Day-Apr

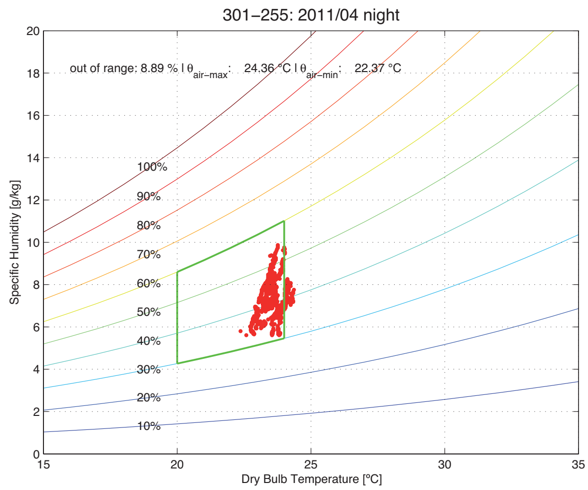

Fig. 174 B - T1-451-Night-Apr

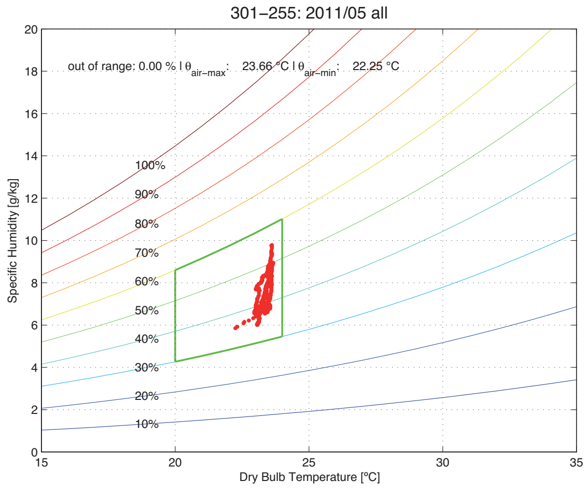

Fig. 175   B - T1-451--Whole Period- May

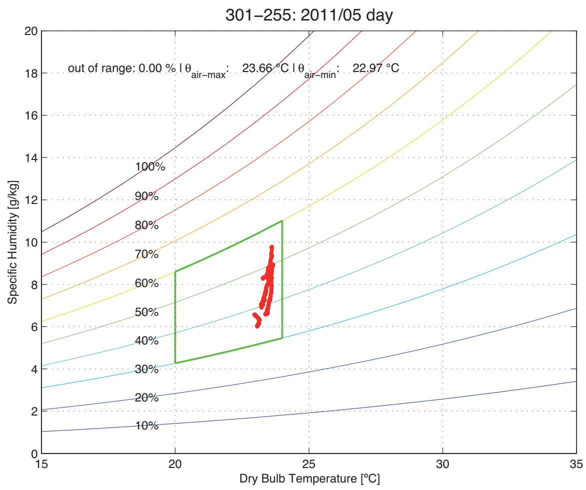

Fig. 176 B - T1-451-Day-May

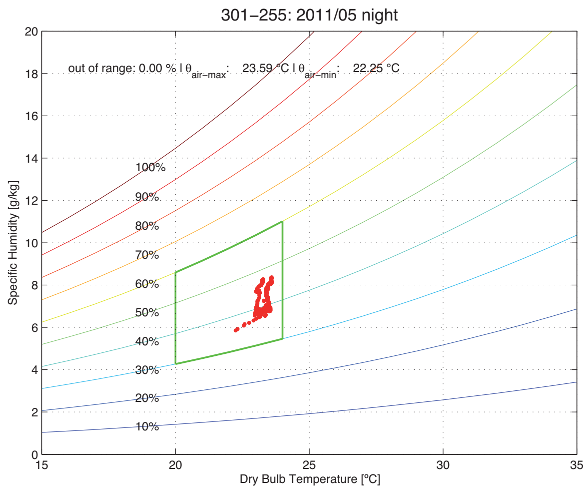

Fig. 177 B - T1-451-Night-May

T1-563

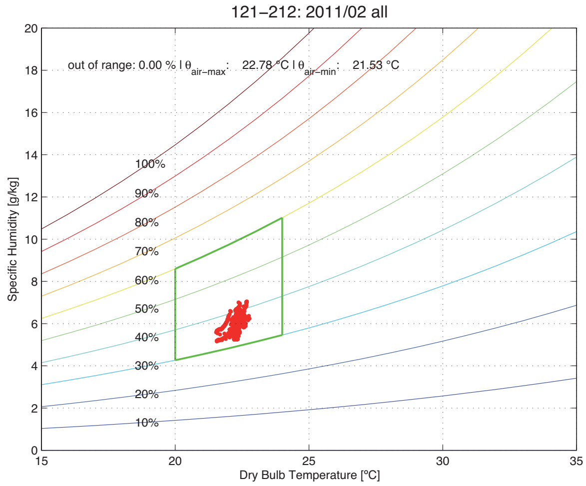

Fig. 178   B - T1-563-Whole Period- Feb

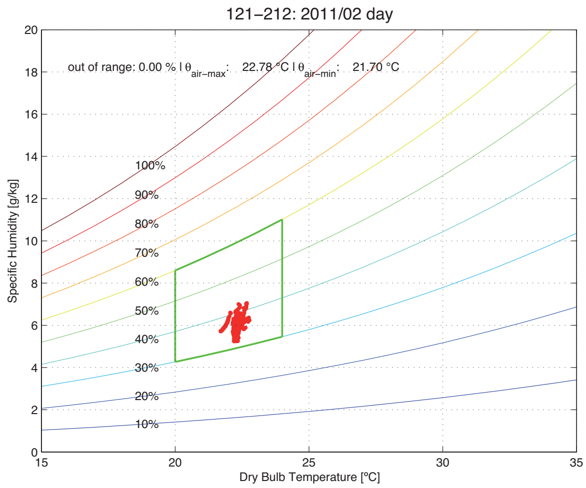

Fig. 179 B - T1-563-Day-Feb

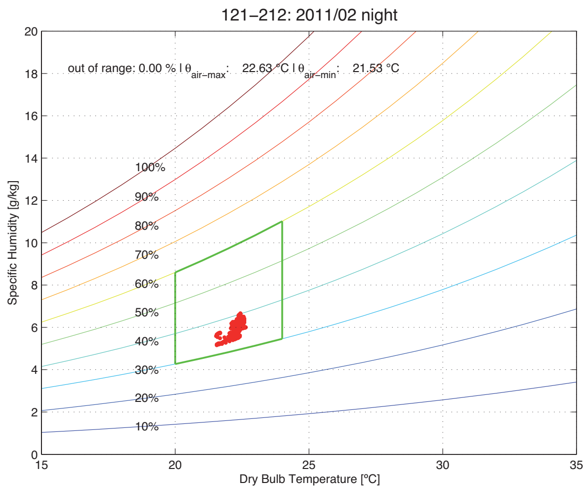

Fig. 180 B - T1-563-Night-Feb

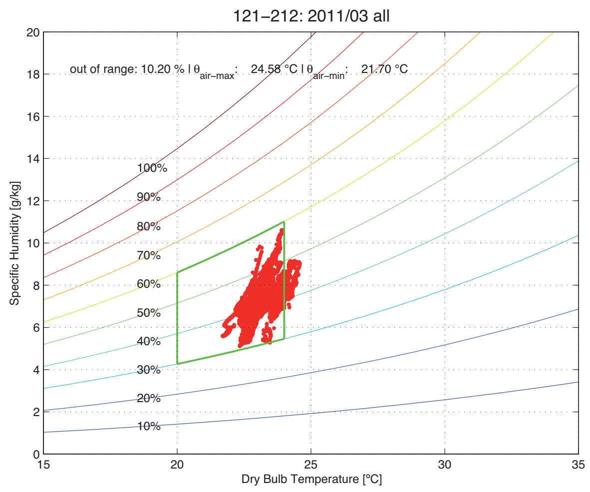

Fig. 181 B - T1-563-Whole Period- Mar

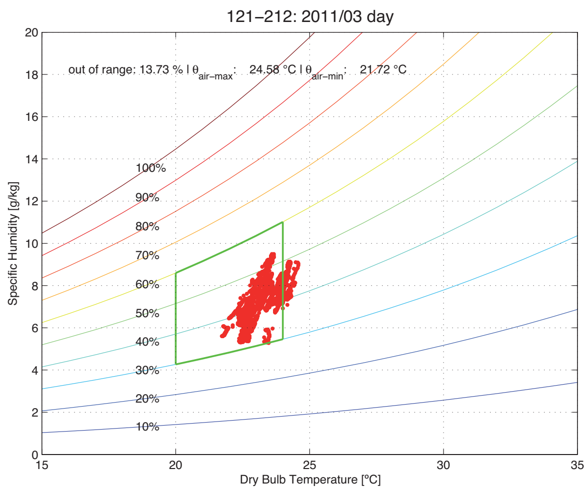

Fig. 182 B - T1-563-Day-Mar

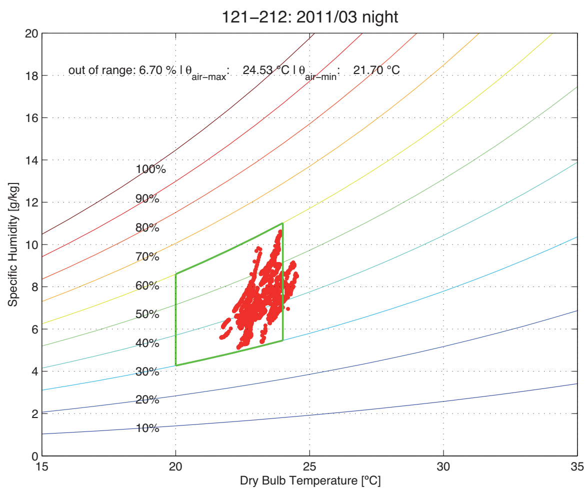

Fig. 183 - T1-563-Night-Mar

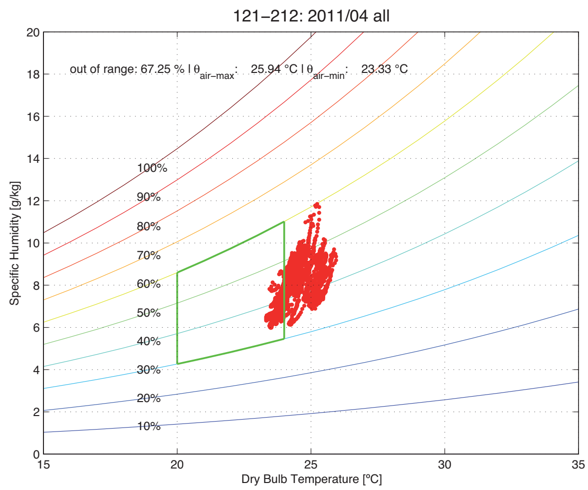

Fig. 184   B - T1-563-Whole Period- Apr

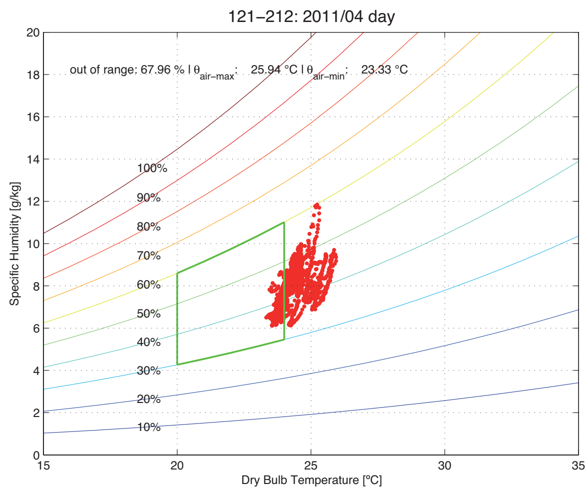

Fig. 185 B - T1-563-Day-Apr

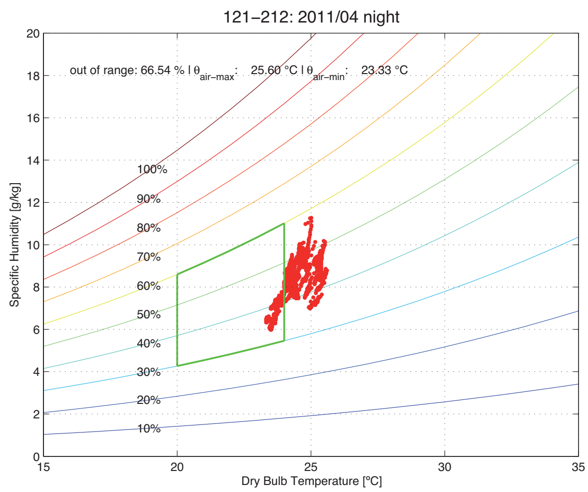

Fig. 186 B - T1-563-Night-Apr

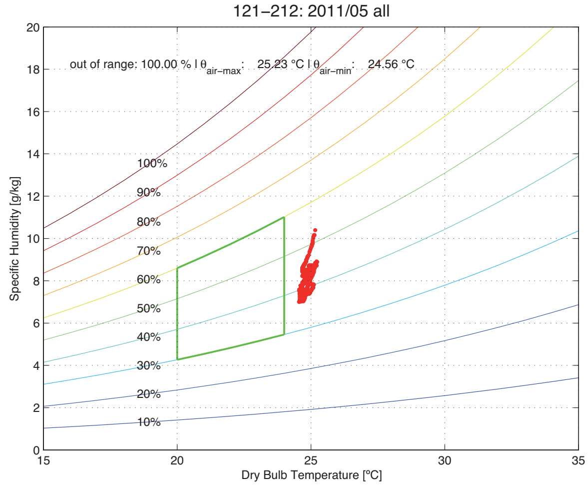

Fig. 187 B - T1-563-Whole Period- May

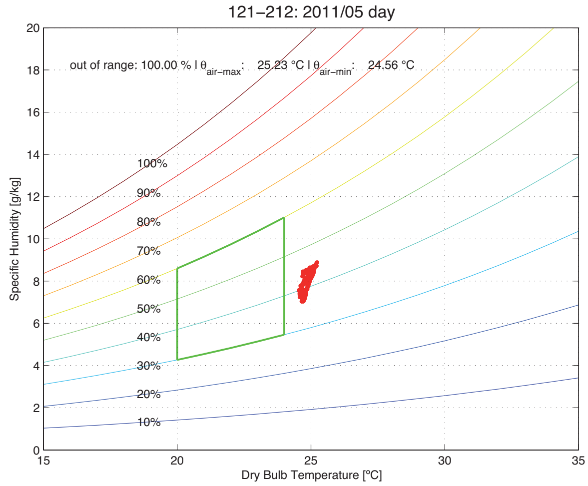

Fig. 188 B - T1-563-Day-May

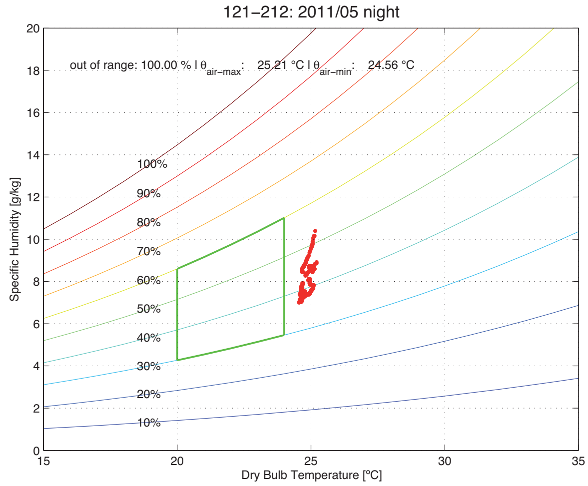

Fig. 189 B - T1-563-Night-May

7.3. Questionnaire

Fragebogen- Questionner
Messungen für die Masterarbeit von Diana Espinosa
Mesurements for the Master thesis of Diana Espinosa

ROOM: ……. Date: ……… Time: ……….

1. How long have you been living in this apartment?

2. Is this your first time living in a Passive House building?

○ yes ○ No

3. Did you read the informational brochure (manual) of the passivhaus?

VENTILATION

4. Without having he windows- how do you feel about the air quality of the room?

Living Room

(+) -- (-)

○ Very Good ○ Good ○ Neutral ○ Fair ○ bad

Sleeping Room

(+) -- (-)

○ Very Good ○ Good ○ neutral ○ Fair ○ bad

5. How do you feel about the air humidity of the apartment?

(+) --- (-)

○ Too dry ○ Dry ○ Neutral ○ Humid ○ very humid

6. Do you feel that there is enough air flow thru ought the apartment?

(+) --- (-)

○ Very Good ○ Good ○ Neutral ○ less good ○ Not good

7. Do you find any issues with smell?

○ Always ○ Often ○ Never

Please explain why:

Fragebogen- Questionner
Messungen für die Masterarbeit von Diana Espinosa
Mesurements for the Master thesis of Diana Espinosa

TEMPERATURE

8. How often do you open the window in the heating season?

○ Always ○ Sometimes ○ Rerely ○ Never

9. How often do you use the radiator (space heater) in the room?

(+) --- (-)

○ Always ○ Sometimes ○ Neutral ○ Almost Never ○ Never

10.How do you feel with the current temperature of the room?

(+) --- (-)

○ Cold ○ Rather cold ○ Neutral ○ Rather hot ○ Hot

LIGHTING

11. Do you feel there is enough natural lighting coming into the building?

○ Always ○ Often ○ Almost Never ○ Never

12. How often do you use the window blinds?

Sunny Days (warm)

○ Always ○ Often ○ Almost Never ○ Never

Winter Days

○ Always ○ Often ○ Almost Never ○ Never

Please explain why if needed

Fragebogen- Questionner
Messungen für die Masterarbeit von Diana Espinosa
Mesurements for the Master thesis of Diana Espinosa

13. Do you ever turn on the artificial lighting during the day because of lack of natural light?

○ Always ○ Often ○ Almost Never ○ Never

Please explain why:

BUILDING SATISFACTION

14. How satisfied are you living in the building?

○ Very Satisfied ○ Satisfied ○ Little Satisfied ○ Not Satisfied

Comments: