Industrial Energy Efficient Retrofitting of Resident Buildings in Cold Climates

D5.5
Guidelines to Operators

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Executive Summary

In this deliverable, the E2ReBuild monitoring scheme is evaluated for all demonstrations. The different monitoring parameters are assessed and the experiences from the demonstrations are highlighted.

A framework for evaluating and visualising tenants' experiences of indoor comfort was developed and implemented by a tenant questionnaire. The indicators covered by the questionnaire were evaluated for all E2ReBuild demonstrations and the qualities related to the experienced indoor comfort are presented in this deliverable. The E2ReBuild demonstrations are evaluated from an indoor comfort point-of-view utilising both the end-user evaluation performed through questionnaires and interviews with tenants, and the monitored indoor data on comfort. The results are compared to the evaluation and outcomes on indoor air temperatures, relative humidities, indoor carbon dioxide levels and airing habits are analysed.

Guidelines for an automatic control system and routines for continuous following-up of indoor environment and energy use are established and compared to the experiences of the E2ReBuild demonstrations.

The last part of this report presents a hygrothermal study on the retrofitted building envelopes of two E2ReBuild demonstrations. To improve their energy performance, the retrofit included a façade refurbishment with the TES method utilizing timber based, prefabricated façade elements for the renewal of the building envelope and improved thermal insulation. As part of the E2ReBuild monitoring programme, hygrothermal gauges were installed in the walls and they have been monitored for more than one year after the retrofitting. In this report the findings from the monitored facades are compared with hygrothermal computer simulations and evaluated.

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1 Introduction

In this report, the E2ReBuild monitoring scheme is evaluated for all demonstrations. The different monitoring parameters and guidelines are assessed and the experiences from the demonstrations are highlighted. The report gives valuable input for following-up of retrofit projects and gives insight to a framework for data collection and analysis.

The framework for evaluating and visualising tenants' experiences of indoor comfort was developed and implemented by a tenant questionnaire. The indicators covered by the questionnaire were evaluated for all E2ReBuild demonstrations and the qualities related to the experienced indoor comfort are presented in this deliverable. The E2ReBuild demonstrations are evaluated from an indoor comfort point-of-view utilising both the end-user evaluation performed through questionnaires and interviews with tenants, and the monitored indoor data on comfort parameters. The results are compared to the evaluation and outcomes on indoor air temperatures, relative humidities, indoor carbon dioxide levels and airing habits are analysed.

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1.1 Key Questions

- What are the lessons learned from the E2ReBuild monitoring programme and how has it contributed to improvements such as adjustments for energy saving measures?
- How is the indoor air quality perceived by the tenants of the E2ReBuild demonstrations?
- What should be included in a guideline for an automatic control system and in routines for continuous following-up of indoor environment?
- How has the E2ReBuild monitoring programme contributed to an increased knowledge on retrofitting of building envelopes utilizing prefabricated façade elements (TES)?

2 Evaluation of E2ReBuild Metering Programme

2.1 Common Monitoring Guidelines

To enable the comparison and evaluation of all 7 demonstrations of E2ReBuild but also previous and future external retrofitting projects, the E2ReBuild guidelines proposed in deliverable D5.1 *Monitoring Schemes for Demonstrations* define a common approach and unified methodology for the demonstrators in the different countries. Information is provided on parameters that are necessary to follow-up and analyse and enable detailed metering and monitoring of the buildings' energy performance and the buildings' indoor environment and thermal comfort for the tenants. This includes suitable measuring methods, precision of metering equipment, frequency of measurements and measurement points. Data on the need for space heating, cooling, hot water, building electricity and household electricity had to be monitored for at least a year after the retrofitting of the demonstration buildings had been completed. The collected data was used to verify that the energy targets for the E2ReBuild demonstrations were met and provide valuable information on best practice examples for the construction sector, as presented in E2ReBuild deliverables D2.1-2.7. The guideline is not intended to provide instructions and references to the use of measurement technology. These are parameters that are necessary to measure in order to meet the minimum criteria of E2ReBuild, enabling the analysis of the overall energy performance, and other parameters that are non-compulsory, but add scientific value and should be included if possible.

2.2 Monitoring of Demonstrations

In order to enable comparison between demo sites and countries, it is essential that the data is collected in the same format and by the same definitions. For instance, in Sweden, the heated area of an apartment or building, is defined in a certain way, but could have a different definition in another country. This will then impact the analysis. Air tightness is another parameter that has different definitions in different countries. The following definitions were used (and measured):

Heated/cooled net floor area [internal] in m²

Floor areas in temperature-controlled (heated/cooled) spaces, enclosed by the inside of the building envelope, see Figure 1.

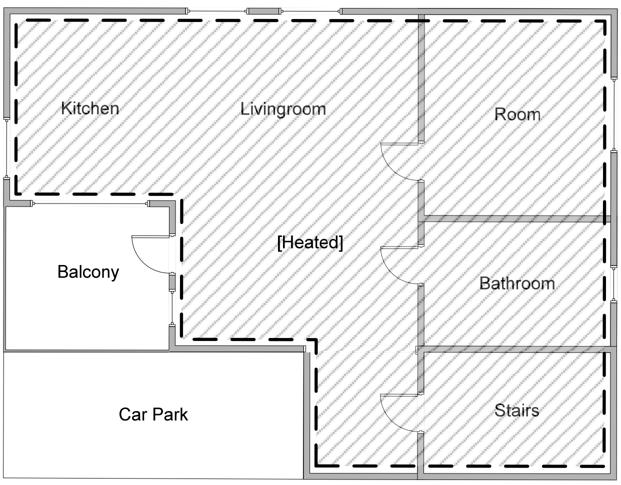


Figure 1: Floor plan for heated/cooled net flood area.

Heated/cooled net volume [internal] in m³

Volumes in temperature-controlled (heated/cooled) spaces, enclosed by the inside of the building envelope, see both Figure 1 and Figure 2.

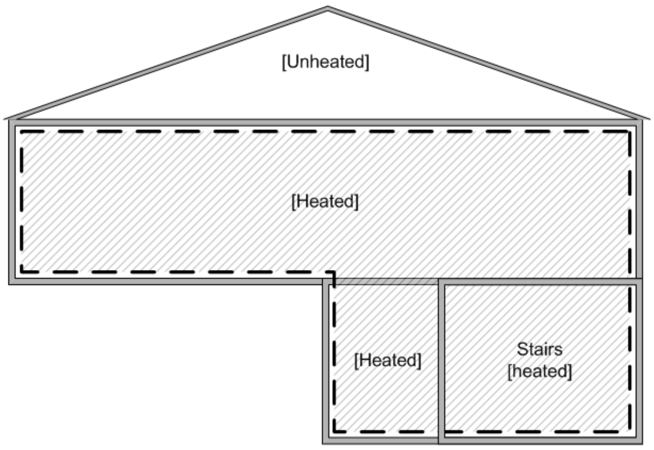


Figure 2: Cross section for heated/cooled net volume.

2.2.1 Monitored Parameters

The results of the measurements are used to compare the energy performance of the demo projects as presented in deliverables D2.1-D2.7. There are several levels of parameters that are possible to measure. The following parameters are required to be measured in the demo projects according to the agreement:

- Purchased energy
- Space heating
- Cooling
- Domestic hot water
- Building electricity
- Household/tenant electricity
- Produced electricity (PV's, wind turbines etc.)
- Produced heat (solar panels)

2.2.2 Additional Monitored Parameters

Some parameters could also be included to make a more detailed study:

- Average temperature difference between inlet DCW temp and supply DHW temp, Δtw [°C]
- Produced electricity [kWh/month]
- Produced heat [kWh/month]
- Ventilation rates
- Air tightness
- Outdoor climate data and weather forecast control system
- Dwelling (indoor) climate data, e.g. temp, RH, CO2, airing
- Building envelope performance data, e.g. temp, RH, moisture in walls

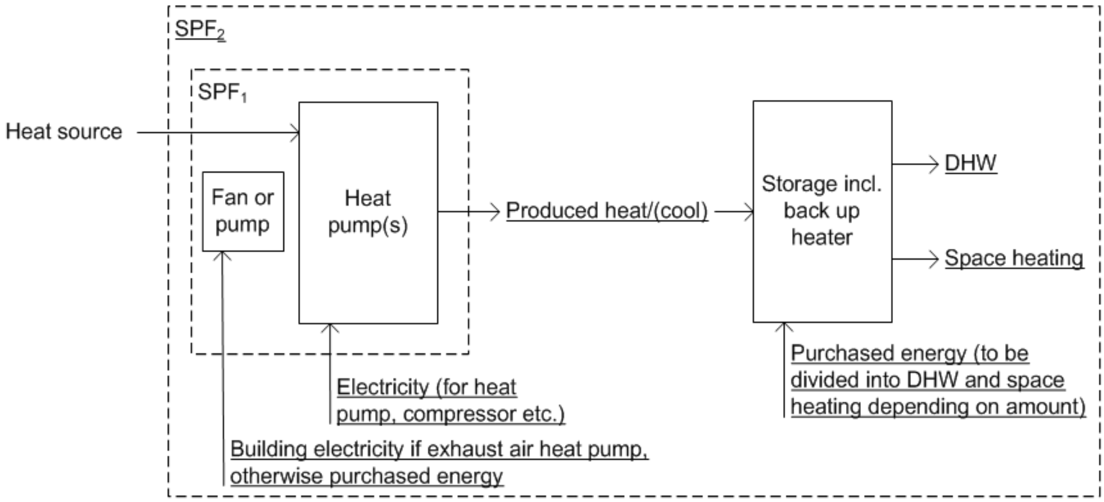
2.3 Experience of Data Collection from the E2ReBuild Demonstrations

In this chapter the experiences from the different E2ReBuild demonstrations are evaluated for the different monitoring parameters. The information was collected through a questionnaire sent out to each demonstration leader.

2.3.1 Purchased Energy

Purchased energy includes energy for heat pumps, gas, district heating, wood pellet burners etc. The purchased energy can be used for many different purposes; district heating could be used to heat the building and DHW, electricity to light up the building and drive fans, pumps and elevators. Depending on the source of energy, the measuring method could differ. Collection of data of purchased energy of district heating, natural gas and similar is often easy since the energy company sends invoices of the cost and amount of energy.

There are a few sources that need special considerations. Electricity for heat pumps is one of them. Heat pumps can be used for several purposes, both for space heating and/or domestic hot water production. A heat pump can also be used for cooling purposes in reverse operation. The methodology in Figure 3 should be used for heat pumps. SPF stands for heat pumps seasonal performance factor.



SPF_1 is only to be used if an evaluation of the heat pump has to be made (not mandatory for the E2ReBuild project).

Figure 3: Heat pump, system boundary [figure made after inspiration from the SEPEMO project]

Considering the different system boundaries in Figure 3, the parameters should (at least) be measured according to system boundary 2. Boundary 1, which includes more parameters, is not necessary to measure in this project. The back-up heater can be of different types, and can be used not only for heating or DHW separately. The amount of each must then be calculated. If it’s an exhaust air heat pump (and the fan is part of the ventilation system), the energy for the fan should be included in the operational electricity. If it’s an outdoor air heat pump, the energy for the fan should be divided into space heating and DHW accordingly (the same for a pump). In Table 1 comments and experiences from the E2ReBuild demonstrations are shown.

Table 1: Experiences from the demonstrations on purchased energy

Purchased energy – experiences from demonstrations			
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**
Munich	Siemens system for building automation.	Automatic reading, local server, via bus system.	Complicated system, only specialists can install and use it.
Oulu	Purchased energy is documented by separate billing from the utility companies for district heat and electricity for the entire property.	Bills forwarded by email from PSOAS.	Electricity, water and heat is distributed from a service building to 5 apartment buildings, so system boundaries (for the demonstration building) are unclear.
Voiron	Energy meter provided by the energy provider, the value is read on the energy display (XXXX,YY m3), no storage available.	Manual reading once a month.	This energy meter allows us to check the overall performance of the heating boiler (on a monthly basis).
Augsburg	Energy contracting system, heating system is provided by public utilities / provider, they bill the energy (here wood pellets).	Manual reading.	-
Halmstad	This is not monitored as a single dataset. The parts must be manually put together to get the total purchased energy.	E-mails once a week, from the building automation provider Kabona's local server.	This is difficult to calculate for the E2Rebuild project because not all of the building is included. The parts which are not included must be taken away from the total.
Roosendaal	<1% (assumed).	SQL database, hourly values, automatic reading (Plugwise).	Smart meter was installed for readings.
London	Gas and electricity monitored as described below.	Data accessible to researchers via web portal.	Calculated from gas and electricity sensor readings.

2.3.2 Space Heating

The amount of energy used for space heating shall be measured. The reason is that it is needed to compare building performance with other similar buildings. There are also often goals (or national requirements) regarding the amount of energy that can be used for space heating.

The measuring method that's applicable and preferred depends on type of heating that is installed. Space heating is always tricky to measure for separate apartments, if the heat is not produced in the apartment (electric radiators or similar). If water radiators or similar are used, many measuring points could be needed. It is also important to keep in mind that an apartment is not only heated by the heating system, but also by electrical equipment in the household, people, solar radiation, surrounding flats etc.

The system boundary for space heating is the building and its apartments, no other spaces and/or business in the building shall be included, see Figure 4. The energy use for space heating shall also be separated from the DHW. Heated stairways and other heated spaces belonging to the apartments should be included. If apartments and non-residential areas share the same heated stairway, its energy use should be divided according to the size of the areas respectively. The heat losses inside the building; from heating pipes etc. must be included.

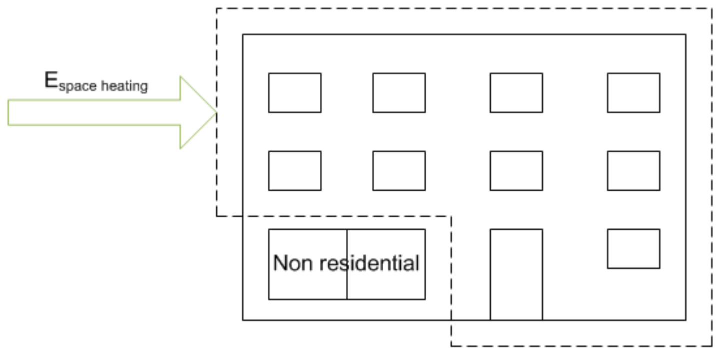


Figure 4: Energy for space heating, system boundary.

There are different types of systems for space heating which require different type of measuring equipment. Space heating systems driven by electricity require some kind of electricity meter, either for each apartment or for the whole building.

Space heating by water requires a flow meter and a temperature meter <u>or</u> a heat meter for the incoming water. A heat meter is often cheaper and easier to use, but it requires a steady flow. For intermittent flow, it is more appropriate to measure the flow and temperature.

If the whole building should be monitored it's preferable that the pipe that supplies the whole building be measured. If possible, each or a few apartments could be measured individually.

When district heating or another energy source supplies the building with hot water for both space heating and DHW, there is only a need for two meters, see Figure 5.

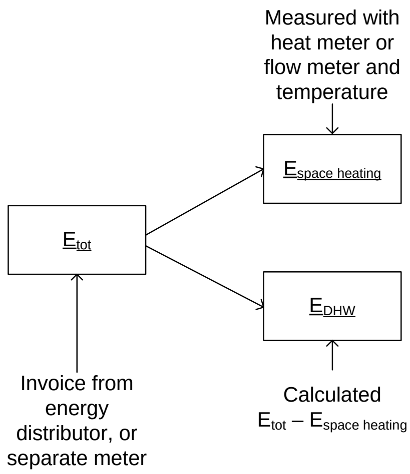


Figure 5: Separation and measurement of space heating and DHW.

The frequency of measurements should be at least once per month, but if possible more frequent.

It is preferred that the data assembly be made without collaboration with the tenants, i.e. no entry to apartments or manual readings.

Table 2: Experiences from the demonstrations on space heating

Space heating – experiences from demonstrations				
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**	**Individual measuring and metering**
Munich	Siemens system for building automation.	Automatic reading, local server and bus.	Complicated system, only specialists can install and use it.	Additional meters for heating due to a separate billing system in each apartment. Only annual bills available for tenants.
Oulu	Calculated by Fidelix FX-2025a Digital Controller. Sensors: Saint-Gobain Sharky 775 ultrasonic compact energy meter measures flow and calculates energy; Produal TEAT NTC10 sensors measure supply and return temperatures.	Online access to FX-2025a Controller and PSOAS central controller.	Online access and data downloading is laborious, since we did not specify output format.	Heating is controlled centrally, but residents can adjust radiators. Residents' optional use of bathroom underfloor heating reduces district heating demand.
Voiron	The value is read on the energy display (XXXX,YY MWh), a storage is available by default for each end of year. A tool can be purchased to program more	Manual reading once a month.	The metering system implemented, allow us to check the good temperature for heating or DHW and energy consumption regarding outdoor climate with weather	No individual energy meter, billing is done according to the dwelling surface. General information about the building and billing will be provided to tenants during a meeting.

	accurate data storage.		data purchased to another organisation.	
Augsburg	Contractor.	Manual reading.	-	Monthly invoice and individual metering with annual billing, no visualisation.
Halmstad	The energy to the floor heating and radiators are monitors.	E-mails once a week, Kabona's local server.	-	No.
Roosendaal	Derived from energy balance, accuracy estimated at 10% (rounded) for typical reference values.	Derived from several measurement data	-	Does not apply.
London	Sensor: Zelsius heat meters installed with pulse output to Cogent-House wireless system; Resolution: 1 kWh; Accuracy: +/- 1kWh; Storage: MySQL database.	Data accessible to researchers via web portal	-	-

2.3.3 Domestic Hot Water

Domestic hot water (DHW) shall be measured to quantify the water and power consumption. Often there are goals of maximum DHW used and to be able to compare the actual consumption to the goal, the consumption must be measured. The consumption of DHW can differ very much in similar apartments, and the reason is that the tenants have different user behaviour. It could therefore be interesting to measure also a few apartments if that is possible.

The consumption of DHW shall be measured at least for the whole building, but preferable (if possible) in all or a number of apartments in the building. Thus it shall not include area that's not apartment area, see Figure 6. If hot water is also used in washing machines (without electricity heating), a separate meter is preferred for laundry equipment.

The measuring system should be adjusted individually according to how the building is built.

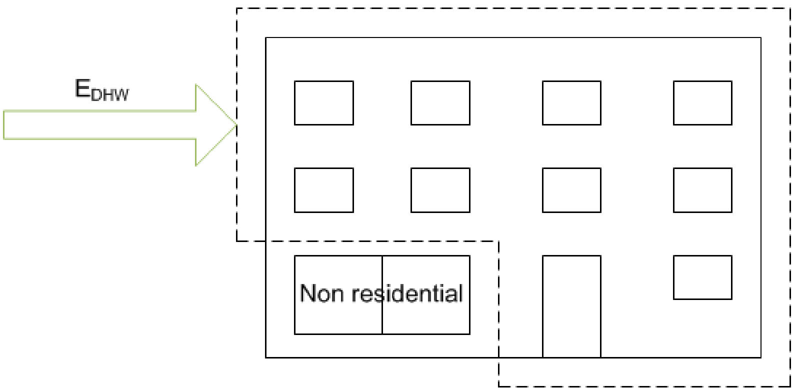


Figure 6: Energy for DHW, system boundary

There are a number of methods to measure the DHW consumption and it is important to separate the total amount of water used from the DHW. Furthermore, the total amount of hot water used, should be separated into hot water for DHW and space heating respectively (this can be the case when district heating, solar heating or similar is used for both space heating and the production of DHW.) If DHW and space heating comes from the same source, it's sufficient if total amount of energy and energy for space heating is measured, see Figure 5. Energy from solar collectors shall be handled according to Figure 9.

The metering equipment to be used depends on how the DHW is produced and distributed. There are a number of different production methods available. The system can also be individual per apartment or single house or centrally produced and distributed. The easiest way to measure the DHW usage is to measure in a main pipe (if possible). Combined with measurement of the DHW temperature (and maybe also the supply cold water temperature) the total consumption of DHW can be calculated. A heat meter is not suitable for intermittent flow; the measurement data will have a high uncertainty. It is important that the flow meter is suitable for the intended flow. Preferably the meter is calibrated or checked before it is installed. One should know that the equipment can measure incorrectly. The long term measurement uncertainty is never the less impossible to foresee (it is also possible to adopt a temperature rise of the water, for example 47 degrees; it is still more uncertain to measure the DHW with a heat meter instead of a volume meter and adopt the flow temperature.)

To measure the consumption in a flat, several meters may be required. Depending on how many pipes that supply the apartment with DHW, the number of meters varies.

The minimum criteria for frequency of measurements are once a month. The consumption shall be logged during the period and, if possible, to be read without visit to a site.

Table 3: Experiences from the demonstrations on domestic hot water

Domestic hot water – experiences from demonstrations				
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**	**Individual measuring and metering**
Munich	Siemens system for building automation.	Automatic reading, local server and bus.	Complicated system, only specialists can install and use it.	Additional meters for DHW due to a separate billing system in each apartment. Only annual bills available for tenants.
Oulu	Saint-Gobain Sharky 775 Ultrasonic Compact Energy Meter used for measuring the energy consumption in heating. The hot water supply to each apartment is equipped with TENA NTC10 temperature sensors and water meter.	Online access to FX-2025a Controller and PSOAS central controller.	Initially hot water readings were erratic, but PSOAS asked the building automation provider Fidelix to adjust the settings.	-

Voiron	The value is ridden on the energy display (XXXX,YY MWh), no storage by default. A tool can be purchased to perform data storage.	Manual reading once a month.	-	Billing done once a year according to individual meters.
Augsburg	Contractor.	Manual reading.		Monthly invoice and individual metering with annual billing, no visualisation.
Halmstad	Flow meter on the cold water feeding the hot water heaters.	E-mails once a week, Kabona's local server.	-	No.
Roosendaal	5% <3 l/h; 2% >5 l/h	SQL database, 3-min values, automatic reading.	-	Does not apply.
London	N/a.	N/a.	N/a.	N/a.

2.3.4 Building Electricity

Building electricity shall be measured in order to compare buildings with each other. Included in the building electricity are the following:

- Fans in the ventilation system
- Pumps for distribution of water for space heating and DHW
- Lighting in common interior spaces
- Lighting in outdoor spaces (if lighting is located on the building)
- Elevators
- Common laundry-room (but should be measured separately if possible)
- Sauna (property electricity if common, otherwise household electricity)

Excluded in the building electricity are the following:

- Lighting exterior spaces
- Car heaters
- Electricity to electric cars
- Electricity to electric bicycles

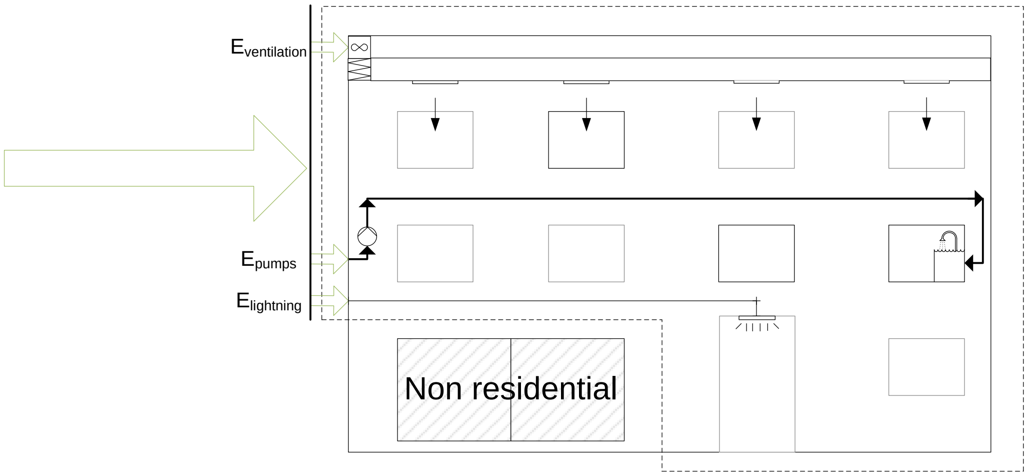


Figure 7: Building electricity, system boundary.

A low usage of property electricity is always desired, but it is important that ventilation, lightning and so on is functioning perfectly and fulfils all demands on safety and good indoor environment.

If possible, it would be interesting if the property electricity is divided into space heating (if applicable in common areas), ventilation, lighting and so on.

There are several possible solutions to get information regarding the property's electricity usage. One method is to get the information from the electricity company, but frequency of measurements depends on what meters they are using. If it's not possible to get measurement data from the electricity company at all or with required sampling interval, new or complementing equipment can be installed. Sometimes it is possible to use an existing electricity meter and log it (by connecting a meter to the pulse output). Otherwise a new electricity meter can be installed and logged.

The frequency of measurements should be at least once a month.

Table 4: Experiences from the demonstrations on building electricity

Building electricity – experiences from demonstrations			
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**
Munich	-	Manual reading.	-
Oulu	Purchased energy is documented by separate billing from the utility company's electricity for the entire property.	Bills forwarded by email from PSOAS.	The property energy is not separately monitored for this building alone, but is the total for all 5 buildings on the property. Data from the utility billing for 2013 is unreliable, because there were renovation works in other buildings. If needed, there are equipment specifications available for the 2 ventilation units and LED lighting in the 2 stairwells that are not being individually monitored.

Voiron	The value is read on the energy display (XXXX,YY kWh), no storage available.	Manual reading once a month	-
Augsburg	Standard electricity metering	-	-
Halmstad	Multiple measurement points.	E-mails once a week, Kabona's local server.	-
Roosendaal	<1% (assumed)	SQL database, hourly values, automatic reading (Plugwise).	Smart meter was installed for readings.
London	Current Cost electricity clamps connected to Cogent-House wireless sensors; data collected on 6 sec interval and summarised over 5 minute intervals; +/- 10% of value; stored in MySQL database.	Data accessible to researchers via web portal.	Issue with proprietary wireless connectivity between current-cost sensor and current cost display may cause data loss.

2.3.5 Household Electricity

The use of electricity in the apartments often differs very much between tenants. Included in the household electricity is the electricity use by the tenants for appliances in their apartment or house, for example lighting, white goods and brown goods.

Space heating or DHW shall not be included.

Sometimes it is possible to get measurement data for the whole building from the energy company. However, this sometimes requires permission from the tenants in order to access the information. Another possibility is to install an electricity meter, or if there already is one installed, log that one. Sometimes more than one meter per tenant is necessary.

The measurement data should be collected at least once a month.

Table 5: Experiences from the demonstrations on household electricity

Household electricity – experiences from demonstrations				
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**	**Individual measuring and metering**
Munich	Not possible due to privacy.	-	-	Separate billing and metering per household.
Oulu	Household and ventilation electricity is monitored for each of 8 apartments. Calculated by Fidelix FX-2025a Digital Controller. Ventilation data collected from ENERVENT PINGVIN eco ECE ventilation units Multi Web-ModBus.	Online access to FX-2025a Controller and PSOAS central controller.	Monitoring of the ventilation units has produced an excess amount of data which obfuscates the monitoring. Additional expertise is needed!	Individual apartments can read their electricity consumption on a daily weekly and monthly basis, but the usability and reliability of these displays has not been reviewed.
Voiron	-	-	-	-
Augsburg	Not possible due to privacy.	-	-	Monthly invoice and individual metering with annual billing, no visualisation.
Halmstad	Electricity provider measures this for billing purposes. We do not have access to the parts and access to the whole building can be difficult.	Electricity provider's system.	-	Separate billing.
Roosendaal	<3%	Derived from measured electricity use.	Installation electricity use measured with three kWh-meters (pulse); +/-1.6%.	Does not apply.
London	Current Cost electricity clamps connected to Cogent-House wireless sensors; data collected on 6 sec interval and summarised over 5 minute interval; +/-10% of value; stored in MySQL database.	Data accessible to researchers via web portal.	Issue with proprietary wireless connectivity between current-cost sensor and current cost display may cause data loss.	-

2.3.6 Produced Electricity

Electricity that's produced by installations on the building (i.e. PV's, small wind turbines) and supplies the building with energy shall be measured. The total amount of energy that the installation produces and the amount of energy sold to the grid shall be measured, see Figure 8.

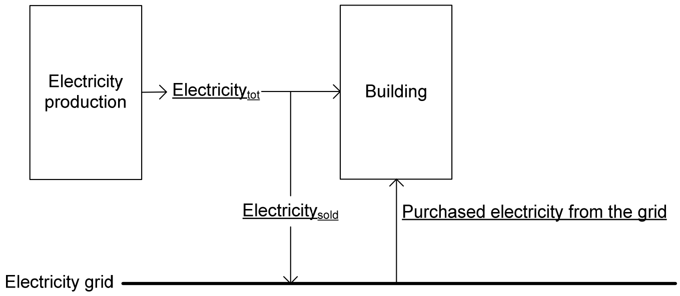


Figure 8: Electricity production and measurement points. The underlined parameters should be measured.

The frequency of measurement should be at least once per month. It may be possible to use some of the data from the energy company.

None of the E2ReBuild demonstrations included produced electricity.

2.3.7 Produced Heat

Heat that is produced by installations on the building (i.e. solar collectors) and is supplied to the building, shall be measured. Solar collectors and other devices like heat pumps shall be handled according to Figure 9. System boundary 2 shall be used; it's an option to measure according to system boundary 1 in order to evaluate the solar collectors more accurately. The frequency of measurement should be at least once per month.

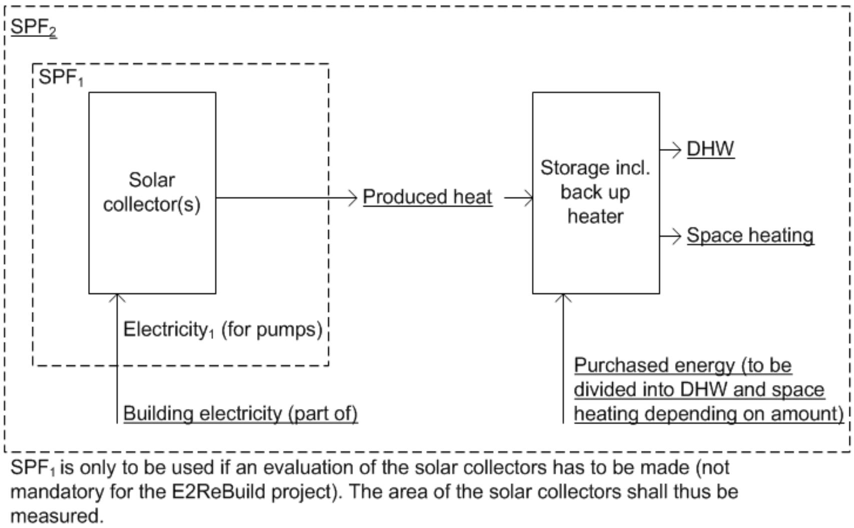


Figure 9: Solar collectors, system boundary.

Table 6: Experiences from the demonstrations on produced heat

Produced heat – experiences from demonstrations				
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**	**Individual measuring and metering**
Munich	Siemens system for building automation.	Automatic reading, local server and bus.	Complicated system, only specialists can install and use it.	-
Oulu	None.	-	-	-
Voiron	The value is read on the energy display (XXXX,YY MWh), a storage is available by default for each end of year. A tool can be purchased to program more accurate data storage.	Manual reading once a month	Several problems were found due to negative water measure. Changes realised in the hydraulic scheme was ok for one thermal solar system but another problem prevent us to measure the last solar thermal system (5 systems on the same building).	No information provided yet. General building and billing information will be provided to tenants during a meeting.
Augsburg	Energy contracting system, heating system is provided by public utilities / provider, they bill the energy (here wood pellets).	Manual reading.	-	-
Halmstad	Heat is produced by the heat pumps. Mitsubishi Zubadan and City-Multi heat pumps. The data is stored on Kabona's server. (Short-term hourly, long-term monthly).	E-mails once a week, Kabona's local server.	More data is monitored by the heat pumps but they are not connected to the system.	No.
Roosendaal	20% based on simplified model for solar collector.	Derived from measurement data + simplified model	No direct measurement of contribution of collector (i.e. no intrusive measurements performed).	Does not apply.
London	N/a.	N/a.	N/a.	N/a.

2.3.8 Dwelling (indoor) Climate Data; Temperature, Relative Humidity and Carbon Dioxide

Temperature is important to measure in order to keep track of the indoor environment in the building and apartments. In the summer it is usual that the temperature gets higher than comfortable, and in the winter the temperature can get too low if the heating system is not working properly or isn't well tuned. If the heating system is not well adjusted, it is also possible that the temperature gets too high even in the winter, especially if the tenants can't adjust the heating system by themselves. Another reason to measure the temperature could be to relate the temperature to the energy used for space heating. A low energy use for space heating is always desired, but should never be done at the expense of low comfort level (among other things low temperature).

The relative humidity (RH) is another parameter that can show if the ventilation isn't working as it should.

Temperature and relative humidity are quite easy to measure. Thus the chosen measurement point is important to get reliable and comparable data. If the temperature and RH are only measured in one room in the flat, the measuring point should be centrally placed. The measuring point should also be placed at an inner wall with no direct sun lightning. The meter should be installed at 1.1 meters height above the floor.

There are several types of suitable measurement equipment available to measure temperature and RH. The system can be either manually or wireless read. It is preferable that it is possible to read the equipment data without disturbing the tenants (e.g. with wireless connection).

Temperature and RH should be measured in a representative number of apartments in the building or houses, and include several rooms, such as living room, bedroom, kitchen. If possible the measurement should be done both before and after retrofitting. The temperature and RH should be logged with a frequency of at least one measuring point per hour.

Carbon dioxide produced by people can be used as a natural tracer gas for air change rate measurements and subsequently indirectly for determining the indoor air quality (IAQ). Comparing the outdoor CO_2 concentration with the measured indoor gives an indication of the quality of the indoor air but does not directly correlate to TVOCs and other hazardous substances such as particles.

The method is commonly used as a surrogate indicator for IAQ and the method can be used for a particular E2ReBuild demonstration. If chosen, the method must be specified according to relevant standards and methods.

Table 7: Experiences from the demonstrations on dwelling climate data

Dwelling climate data – experiences from demonstrations				
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**	**Individual measuring and metering**
Munich	Siemens system, temperature, RH, CO2, ventilation rate.	Automatic reading, local server and bus.	Complicated system, only specialists can install and use it.	Exemplary dwellings, not whole building.
Oulu	CO2: Produal HDK in two apartments, data collected via ENERVENT PINGVIN eco ECE	Online access to FX-2025a Controller and data storage at the PSOAS	Simple Temp/RH monitoring seems to be reliable, since WUFI simulation results support the	Each apartment has a FIDELIX Multi-LCD room panel with 3,5" colour LCD touch screen, programmed to

	ventilation units Multi Web-ModBus. Air supply and exhaust temperature and humidity data is collected in all apartments from all ENERVENT PINGVIN eco ECE ventilation units. Room temperature and relative humidity is measured in 4 rooms in two apartments. Equipment Produal KLH100 measures room temperature and RH. Airing and balcony doors not monitored, but ventilation units provide real time monitoring.	central controller.	monitored data quality. Ventilation units provide too much data which is difficult to collate and sort. Data mining and database management software specialist required!	display hot and cold water volume, electricity meter and outdoor temperature, daily, weekly and monthly use. Usefulness and accuracy has not been checked!
Voiron	Individual measure had been performed (summer and winter period) for around 2 weeks for indoor temperature for 4-5 dwellings.	Storage with data logger.	-	No information provided. General building and billing information will be provided to tenants during a meeting.
Augsburg	Automatic logging with Akktor home automation system (www.akktor.de), sensor with Enocean technology, data: temp, RH, CO2, window opening.	Hourly logging, local storage, monthly reading of data.	Pre-configured system from Akktor works well, maintenance is more complicated than installation because expert knowledge is required, software is not very user friendly.	-
Halmstad	Temperature sensors in a few apartments. At least one or two on each floor.	E-mails once a week, Kabona's local server.	-	Yes, but limited in number.
Roosendaal	ELTEK GD47; T +/- 0.35K; RH +/- 2.5%; CO2 +/-(60+3% reading) ppm.	SQL database, 3-min values, automatic reading.	User behaviour and lay-out of room and equipment used may affect results directly. Limitations in freedom to position instruments.	Does not apply.

London	Sensor: Sensors integrated to the Cogent-House wireless system include on-board temperature and relative humidity, CO_2, and black bulb. Storage: Stored in MySQL database.	Data is stored in MySQL database and accessible to researchers via portal.	-	-

2.3.9 Outdoor Climate Data and Weather Forecast Control System

The reason to measure outdoor temperature and RH is to be able to compare indoor temperatures, RH and energy usage for space heating. Irradiation and wind (speed and direction) should also be measured. Measuring points for temperature and RH shall be located in the shade and preferably kept out of the rain, wind and so on. It should be placed where it represents the outdoor air temperature for the whole area if possible. The other sensors shall be placed where suitable.

There are several suitable brands of metering equipment on the market to measure the temperature and RH. There are systems with either manual or wireless reading.

The temperature and RH should be logged with a frequency of at least one measurement point per hour. The wind speed should be measured with an average over an hour. The irradiation should be measured with a frequency of 10 minutes.

Table 8: Experiences from the demonstrations on outdoor climate data and weather forecast control system

Outdoor climate data and weather forecast control system – experiences from demonstrations			
	Instrumentation description (accuracy)	**Data storage and display**	**Comments and experiences**
Munich	Siemens system, temperature, solar radiation.	Automatic reading, local server and bus.	Complicated system, only specialists can install and use it.
Oulu	Davis Vantage Pro2 Plus weather station on service building roof collects local weather data for data comparison. The weather forecast is not used to control the heating supply.	Online access to FX-2025a Controller and data storage at the PSOAS central controller.	Outdoor data from the Davis weather station was not systematically formatted and provided uncertain quality with occasional wild values and data breaks. Therefore benchmark data was collected from Finnish Meteorological Institute open data source with some difficultly. There was a need for machine language programming, but E2ReBuild funding was not available.
Voiron	Individual measure has been performed (summer and winter period) for around 2 weeks, for outdoor temperature.	Storage with data logger.	-

Augsburg	Weather station type Davis vantage pro2 plus, no weather forecast control.	Hourly logging, local storage, monthly reading of data.	Simple and easy out of the box system. Software is not very user friendly.
Halmstad	Weather station on the roof of the building.	E-mails once a week, Kabona's local server.	-
Roosendaal	Radiation: +/1%; wind: +/-3%, min +/-0.5m/s (range: 0.5-35 m/s (-10oC-+40oC); temperature: +/-0.5K; RH: +/-2%RH (0-90% RH), +/-3% RH (90-100% RH)	SQL database, 10-min values, automatic reading + hourly data Meteorological institute.	Weather station located at apartment building nearby. Especially wind difficult to assess locally. Data from nearby meteorological stations applied as well. Good agreement on temperature, RH and solar irradiation.
London	Sensor: Vantage pro 2 weather station, measuring temperature, humidity, wind speed, wind direction and rain. Resolution: Temperature: 0.1°C Humidity: 1% Wind Speed: 1mph Wind direction: 1° Rainfall: 0.01” Accuracy: Temperature: +/-0.5°C Humidity: +/- 3% Wind Speed: +/- 5% Wind direction: 3° Rainfall: +/- 4% Storage: Online portal provided by WeatherLink.com.	Data is stored in an online portal provided by WeatherLink.com.	-

2.4 Lessons Learned from Using the Metering Programme

Has the measured data from the monitoring programme contributed to adjustments for energy saving measures?

Table 9: Experiences from the demonstrations on outdoor climate data and weather forecast control system

Lessons learned – experiences from demonstrations	
Munich	The solar collector system had a malfunction and could be readjusted due to monitoring. Additionally some pumps and valves which were not working properly could be repaired.
Oulu	The demonstration project has been occupied for one year, so it is now possible to evaluate the building energy performance. PSOAS has a building automation controller which displays equipment alarms. The air tightness survey revealed air leaks from the ground floor slab which later was detected by residents as an indoor air quality risk, so the air tightness survey should have been acted on immediately.
Voiron	DHW had higher temperature at different points of the installations (storage tank, go and return pipe to and from the dwellings) was higher than expected in the water tank: it was lowered. Heating temperature is higher than expected despite good values in the heating regulator. A solution is being search for together with the provider and the energy consultancy (March 2014).
Augsburg	Not really, the system works ok.
Halmstad	Yes. The measured data was essential for the energy savings program in the Halmstad project. There is no such thing as an out of box solution when it comes to buildings. The measurement data was needed to fine-tune the system. For instance the functions in the software were not correct and the heat pumps put out too much power and shut down after a short time. They needed to wait for a minimum time on standby before they could start again. In addition, we could also see that the indoor temperatures were unevenly distributed: being warmer in the middle of the building and cold on the top floor. This was due to the deactivation of the floor heating in the attic. The heat flow to the top floor was readjusted so that the top floor received more heat.
Roosendaal	No changes were made during the monitoring period in 2013. Options for improvement are identified.
London	N/a.

3 Evaluation of Indoor Environment

Within E2ReBuild the tenants' indoor environment has been evaluated by a tenants' questionnaire common for all demonstrations as well as monitoring in a representative number of dwellings. In this chapter the background on indoor environment and thermal comfort is explained and the findings from the questionnaire and monitoring is presented and analysed.

3.1 Background

Thermal comfort can accurately be defined as the state of mind which expresses satisfaction with the thermal environment, and therefore, it depends on the individual's physiology and psychology (ISO 7730, 2005[1]). Research conducted in the field of thermal comfort has proved that the required indoor temperature in a building is not a fixed value and quite often difficult to determine and meet.

3.2 "Schools" of Thought for Determining Thermal Comfort

1. The heat balance model, whose main proponent is Ole Fanger[2], is shown in Figure 10. This approach considers the steady-state thermal equilibrium of the following factors:
    a. Air temperature
    b. Humidity
    c. Mean radiant temperature
    d. Air movement (specifically velocity)
    e. Metabolic rate
    f. Clothing level

→ **PMV & PPD**

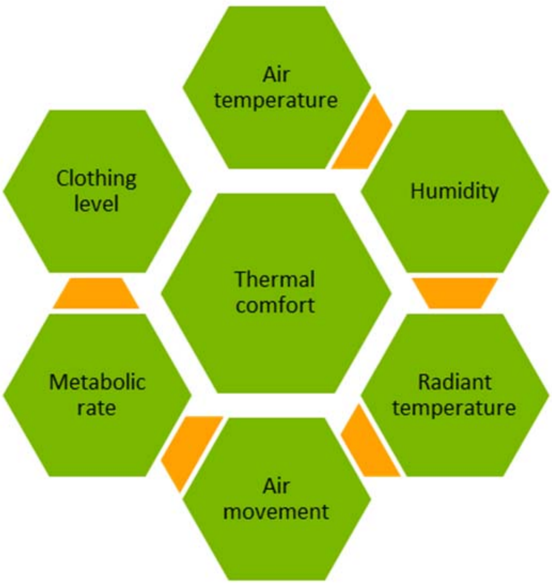


Figure 10: The heat balance model for determining thermal comfort.

These factors can be combined into an equation for predicting thermal comfort (Predicted Mean Vote, PMV) and Percent People Dissatisfied (PPD). The equations developed by Fanger were based on tests conducted in tightly controlled climate chambers.

[1] ISO 7730:2005 Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
[2] Fanger, P. Ole (1970). Thermal Comfort: Analysis and applications in environmental engineering. McGraw-Hill.

2. The adaptive comfort model proposes that thermal comfort is dependent on the history or "memory" of recent weather patterns, culture of the location, and expectations of the building occupants. Adaptive comfort theory is based on building occupant surveys rather than on climate chamber tests.

The figure below, Figure 11, shows how comfort temperatures of an indoor space are dependent upon the outdoor air temperature. Furthermore, it shows the range of comfort temperatures in order to achieve 90% of people satisfied (or 10 PPD shown in blue) and 80% of people satisfied (or 20 PPD shown in green).

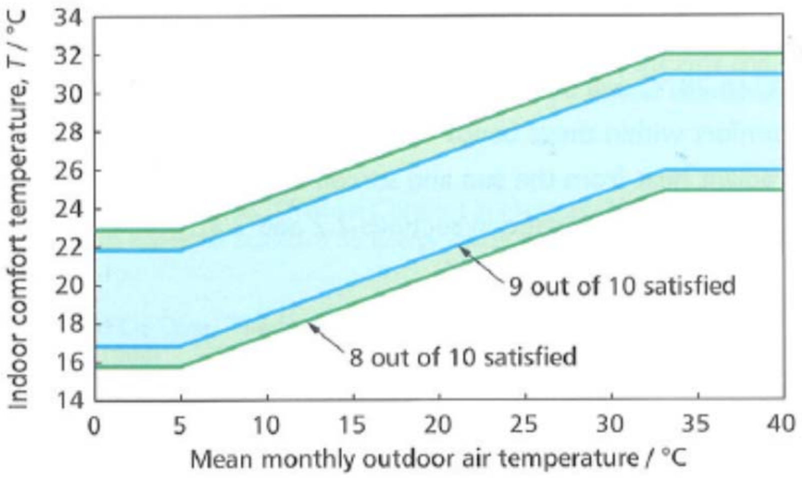


Figure 11: Relation between outdoor air temperature and comfort temperatures of an indoor space.[3]

The next figure shows how comfort temperatures (called "limiting temperatures" in the figure) differ depending on whether a space is naturally ventilated (operated in "free-running" mode) or mechanically ventilated (operated in "heated or cooled" mode). It is clear that, with a naturally-ventilated space, comfortable temperatures can be higher (than those of a mechanically-ventilated space) on a hot day or lower on a cold day. This has significant energy implications for buildings running in hybrid mode.

[3] ANSI/ASHRAE Standard 55-2013, Thermal Environmental Conditions for Human Occupancy.

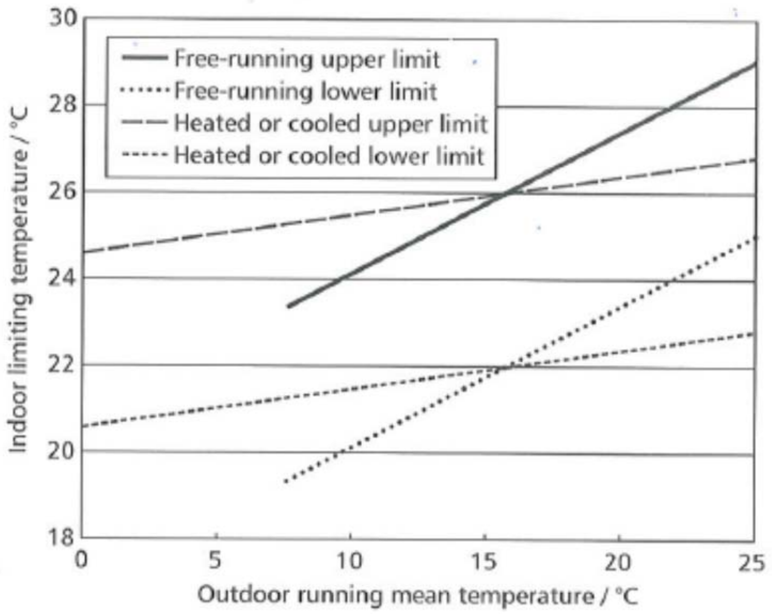


Figure 12: Dependency of ventilation type with acceptance of indoor temperatures by the tenant.[4]

An important factor of thermal comfort is the operative temperature, which is a comfort temperature obtained by combining the dry bulb temperature and mean radiant temperature. In determining overheating risk in naturally-ventilated buildings, the operative temperature is used as the indicative measurement. There is currently no universally-agreed index for measuring thermal comfort. However, some indices of thermal comfort that are currently used include the following:

- Comfort votes (PMV, PPD); different thermal scales are as follows:
- ASHRAE Thermal Scale
- Bedford Scale
- Draught Rating (DR)
- Effective Temperature (ET*)
- Optimal Operative Temperature
- Equivalent Temperature

3.2.1 General Design Considerations for Thermal Comfort

The first thing a mechanical engineer should consider when designing for space conditions is to ask whether the space needs to be designed for thermal comfort or for health reasons (*e.g.*, heat stress). Once it has been determined that the space is to be designed with thermal comfort in mind, it is then important to understand what the space is intended for. Will it be an office? A meeting room? A dining area? A gymnasium? All of these spaces have different heat gains from equipment, lighting, or occupant metabolism. It is also useful to make an educated guess on level of clothing the occupants will be wearing.

The building regulation standards to keep in mind when looking at thermal comfort are as follows:

- ISO 7730 (UK & Europe)
- ASHRAE Standard 55-2004 (US)

[4] CIBSE Guide A: Section 1.6.4.1. CIBSE 2006

3.2.2 Recommendations on Temperature Levels

From the above, it becomes evident that it is impossible to determine comfort by just defining the levels of indoor dry bulb temperature. However, in order to simplify the problem and derive a scale of acceptable comfort levels during summer and winter, a set of recommended values from CIBSE Guide A[5], section 1.3 is displayed below. The table refers to residential spaces such as living room, kitchen, bedroom, toilet, etc.

Table 10: Scale of acceptable comfort levels during summer and winter.

Room type	Winter Operative Temperature range for activity and clothing levels			Summer Dry Resultant Temperature range for activity and clothing levels		
	Temperature(°C)	Activity	Clothing	Temperature(°C)	Activity	Clothing
Bedrooms	17-19	0.9	2.5	23-25	0.9	1.2
hall/stairs/landings	19-24	1.8	0.75	21-25	1.8	0.65
kitchen	17-19	1.6	1.0	21-23	1.6	0.65
living rooms	22-23	1.1	1.0	23-25	0.9	1.2
toilets	19-21	1.4	1.0	21-23	1.4	0.65

However it has to be noted that those are operative temperatures. As the surface temperatures will be somewhat different from the dry bulb ones, the comfort scale used in our cases are a bit stricter with minimum temperature of 19°C and maximum of 24°C. An example of how this can be presented is shown in Figure 13, with the written percentages indicating the intervals for “temperature 1”. In this example, 93% of the time for “temperature 1” falls within the optimum temperature range.

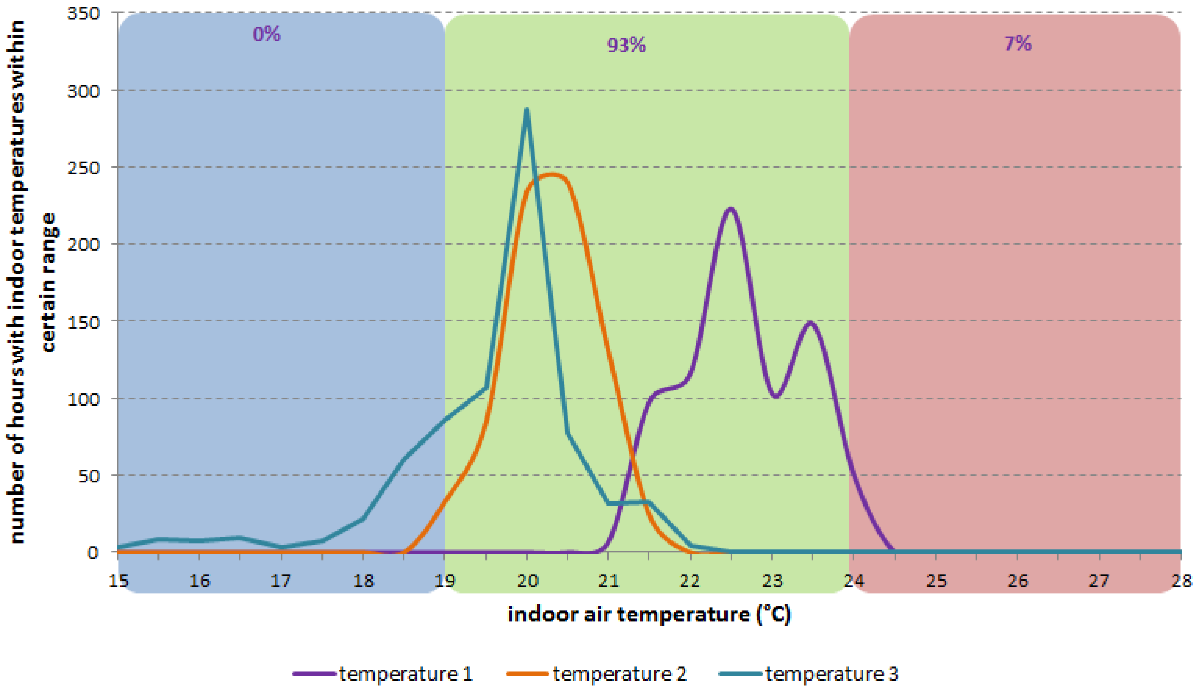


Figure 13: Example of presentation of indoor air temperature related to number of hours within certain range.

[5] CIBSE Guide A: Environmental design - Section 3: Thermal properties of buildings and components, CIBSE 2006

3.2.3 CO_2 Concentration Levels

According to the existing literature, the effects of increased CO2 levels on adults at good health can be summarized:

- Normal outdoor level: 350 - 450 ppm
- Acceptable levels: < 600 ppm
- Complaints of stiffness and odours: 600 - 1000 ppm
- ASHRAE and OSHA standards: 1000 ppm
- General drowsiness: 1000 - 2500 ppm
- Adverse health effects expected: 2500 - 5000 ppm

The recommendations according to the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE, ANSI/ASHRAE 62-1989) are of a maximum of 1,000 ppm CO_2 for indoor spaces.

According to the Standard, "Human occupants produce carbon dioxide, water vapour, particulates, biological aerosols, and other contaminants". Carbon dioxide concentration has been widely used as an indicator of indoor air quality. Comfort (odour) criteria are likely to be satisfied if the ventilation rate is set so that 1000 ppm CO_2 is not exceeded. In the event CO_2 is controlled by any method other than dilution, the effects of possible elevation of other contaminants must be considered.

3.2.4 Relative Humidity (RH) Suggested Levels

Humidity is the amount of moisture in air. This moisture is also known as water vapour. Also the moisture in air can be regarded as low pressure steam.

Unlike the other measures of moisture, relative humidity the most familiar term is not an absolute measure of moisture content. Rather, as its name suggest, it is a measure only of the relative amount of moisture contained by air.

Relative humidity is not really considered to be of vital importance in human comfort since body tolerances are quite wide. We tolerate a low humidity of about 40%, but with even lower values complaints are made of dry skin and dryness of the eyes.

According to "CIBSE Knowledge Series KS6 - Comfort – 2006", relative humidities below 30% can result in shocks due to static electricity, and below about 25% can cause eyes and skin to feel dry. Levels above 80% feel very sticky and uncomfortable, and can lead to condensation and mould growth on building surfaces. The air can feel very stale and stuffy at high relative humidities. CIBSE Guide A(1) recommends that relative humidities in the range 40–70% RH are generally acceptable.

3.3 Indoor Environment Evaluation of the E2ReBuild Demonstrations

A common tenant questionnaire was produced in collaboration with WP3, translated and distributed to all demonstration projects. The aim of the questionnaire was to evaluate the renovation from a tenant perspective and to get insight on more general attitudes on participation, inclusion and energy behaviour.

The situation before and after was compared through the following aspects:

- Well-being and health (indoor comfort and equipment standard)
- Experience of the built environment (proudness, quality of life, security)
- Evaluation and use of technical systems (heat and ventilation control)
- Architectural quality (of floor plan and room design)

For an evaluation of the renovation process and on more general issues concerning involvement and attitudes toward energy behaviour the following aspects were covered:

- Retrofit design and process (participation and information during retrofit, value of retrofit)
- Collaboration and participation (involvement in decision regarding house/apartment)
- Energy behaviour (awareness and interest in energy behaviour and willingness to change)

The questionnaire consisted of both open questions, where the tenant could write their own answers and check-box questions.

Table 11: Framework for evaluation of social impacts.

Framework for evaluating social impacts	
Aspect	**Indicator**
Well-being and health	- Access to natural light - Noise protection (from within building) - Noise protection (from outside building) - Summer temperature - Winter temperature - Exterior wall indoor surface temperature - Draught from windows - Air quality (particles of dust and dirt) - Air quality (smell) - Indoor moisture/humidity - Kitchen equipment standard - Bathroom equipment standard - Overall indoor comfort
Experience of the built environment	- Quality of life is high in my apartment/house - Quality of life is high in my building - Quality of life is high in my neighbourhood - I´m happy with my apartment/house size - I´m happy with my building size - I feel safe in my apartment/house - I feel safe in my building - I feel safe in my neighbourhood - I feel proud of my apartment/house - I feel proud of my building - I feel proud of my neighbourhood - The status of my neighbourhood is high - Where I live is important for my identity - My apartment is important for my identity - I feel a strong connection to where I live now - I belong to the community in my neighbourhood
Architectural qualities	- Floor plan design in your apartment/house - Materials and surfaces - Windows - Light condition - Kitchen - Bathroom - Toilet - Living room - Bedroom - Floor plan design of your building - Balcony - Staircase - Elevator - Building roof - Building facade - Building entrance - Storage closet - Communal sauna - Laundry - Club room
Information, communication and value of retrofit	- Communication before retrofit - Information distributed about the retrofit - Participation from tenants in the design phase - The suggested design proposal - Work in the apartment during retrofit - Value of retrofit in relation to rent level

	- Overall impression of retrofit process - Overall impression of retrofit outcome (the design) - Information to correctly use heating and ventilation system
Energy behaviour	- Is your energy use an important aspect for you? - Are you aware of your energy use? - Are you interested in reducing your energy use? - Would it be possible for you to reduce your energy use? - Has the retrofit made you more aware of your personal energy use?

Many of the aspects covered by the end-user evaluation are analysed and discussed in the E2ReBuild deliverable D3.3 Evaluation of Case Studies and Demonstrations with the focus of Added Values. In this report, focus is tenants' experiences of indoor environment, while energy behaviour is evaluated for the E2ReBuild demonstrations in deliverable D5.4.

As part of the E2ReBuild monitoring programme, *Deliverable D5.1 Monitoring Scheme for Demonstration Projects*, the indoor environment was also evaluated by measurements. To enable the comparison and evaluation of all demonstrations of E2ReBuild but also previous and future external retrofitting projects, the guidelines define a common approach and unified methodology for the demonstrators in the different countries. Information is provided on parameters that are necessary to follow-up and analyse and enable detailed metering and monitoring of the buildings' energy performance and the buildings' indoor environment and thermal comfort for the tenants. This includes suitable measuring methods, precision of metering equipment, frequency of measurements and measurement points. The collected data is used to verify that the energy targets for the demonstrations are met and provide valuable information on best practice examples for the construction sector.

3.4 The E2ReBuild Questionnaire

The following section describes the impact on indoor environment generated by the retrofit process for 6 of the E2ReBuild demonstration projects, from the tenant perspective. The means for the analysis is the tenant's experience of the retrofit process and its impact.

The basis of the analysis was a tenant questionnaire that was distributed to all demos, except London which was still under renovation at the time of having to finalise the evaluation and the deliverable.

3.4.1 Means of Distribution at each Demo

Table 12: Summary, means of distribution and answering rate tenant questionnaires.

	Means of distribution and answering rate, tenant questionnaire
Munich	Printed questionnaires were sent out to all demo households, 10 months after finished renovation. 18 out of 46 households answered the questionnaire. The questionnaire only evaluated the after perspective, given that the demo was evicted prior to the renovation. The questionnaire was distributed and collected during February-March 2014.
Oulu	The demo consists of 8 apartments in a two-storey student accommodation building. Before renovation 3 phone interviews and 2 personal interviews were conducted in July 2012. The after perspective was gathered through an electronic questionnaire distributed by email to 4 households in March 2014. These were the only households resident in November 2013 - March 2014.
Voiron	Interviews based on the questionnaire were conducted by phone. A total of 10 phone interviews were conducted in February 2014. The interviews consisted of both before and after evaluation.

Augsburg	Printed questionnaires were sent out to all demo households, 10 months after finished renovation. 23 out of 60 households answered the questionnaire. The questionnaire consisted of both before and after evaluation. The questionnaire was distributed and collected during February-March 2014.
Halmstad	Printed questionnaires were sent out to all demo households 12 months after finished renovation. 28 out of 71 households answered the questionnaire. The questionnaire consisted of both before and after evaluation. The questionnaire was distributed and collected during November-December 2013.
Roosendaal	Interviews based on the questionnaire were conducted by personal visits at 7 out of 70 demo households, in March 2014. The interviews consisted of both before and after evaluation.
London	The London demo was still under renovation, May 2014, when the deliverable went into review, why this demo is excluded from the evaluation.

3.4.2 Interpretation and Validity of Data

Each of the indicators listed in Table 11 represents a question within the questionnaire. The tenant, when answering the questionnaire, was asked to evaluate each indicator from 1 to 6, where 1 represents the lowest score and 6 the highest. In the below analysis each aspect, for each demo, is forming a value diagram in which all indicators are evaluated, before and after. When interpreting the data the score 1-3 represents not pleased/not positive, 4-6 represents pleased/positive. The evaluation of each indicator is done by summing up the percentage of tenants that are pleased/positive with this particular indicator, for example “access to natural light” or the “floor plan design of apartment”.

In all demos, except Oulu, the evaluation of the situation before and after was done after the completion of the renovation, within the same questionnaire/interview. In Oulu it was, within the time frame of the E2ReBuild project, possible to interview the tenants living in the dwellings before and after which was done because the tenant stock would change. The motivation for evaluating before and after within the same questionnaire/interview at the other demos was to collect the personal experience and comparison of the before and after situation.

The choice of this method for summarising the results was motivated by reducing the impact of an individual answer in the overall evaluation of each indicator.

Given the variety of respondents, from 4 in Oulu to 28 in Halmstad, a consequence of the variety of number of households in the different E2ReBuild demo projects, the below presented statistics should be interpreted with great care. The validity of the results can be questioned by the variety in answering rate and the different means of collecting the data. The questionnaire in Halmstad, Augsburg, Munich and partly in Oulu was done by a printed questionnaire giving the tenants more time to fill in and reflect on the answers. In Roosendaal, Voiron and partly in Oulu[6] the interviews was conducted by phone or personal interview, giving the tenants less time to think about their answers and possibly they further feel less inclined to be critical. Although, the questionnaires gave insights that should not be neglected or underestimated, as they represents the experiences made by the people living at the centre of the renovations, forming their lives around it and suffering or benefitting from the changes the renovation undeniably causes.

The summary which ends each demo evaluation focuses on highlighting indicators where strong changes have occurred in comparison before and after. Motivation for these changes will also be made, with reference to comments from tenants.

[6] The Before evaluation in Oulu was done by verbal interview (3 over telephone, 2 in person in the tenant's homes)

For further reading regarding the demonstration projects; Deliverable 3.1 describes and evaluates adopted stakeholder collaboration models (also including the tenants involvement), Deliverable 4.2/3 describes adopted technical systems and Deliverables under work package 2 (D2.1-D2.7) gives a full description of each demo retrofit. Also, Deliverable 3.3 *Evaluation of Case Studies and Demonstrations with the focus of Added Values* and Deliverable 5.4 *Guidelines to End-users/Tenants*, describes and analyse the indicators above not covered by this deliverable.

3.4.3 Experiences from the End-user Evaluation – Focus on Tenants' Indoor Environment

For the assessment of the E2ReBuild demonstration tenants' experiences on indoor environment, indicators on their well-being and health were evaluated by a questionnaire, as described in Table 11: Framework for evaluation of social impacts.

The tenants' experiences are later compared in Chapter 3.6 to the experiences found from the monitoring programme and the evaluation of monitored comfort parameters as presented in Chapter 3.4.4.

3.4.3.1 Munich - Tenants' Evaluation

In the Munich demonstration the evaluation was carried out after the retrofit. Since the previous tenants were evicted prior to the retrofit, no answers are given for the pre-retrofit conditions.

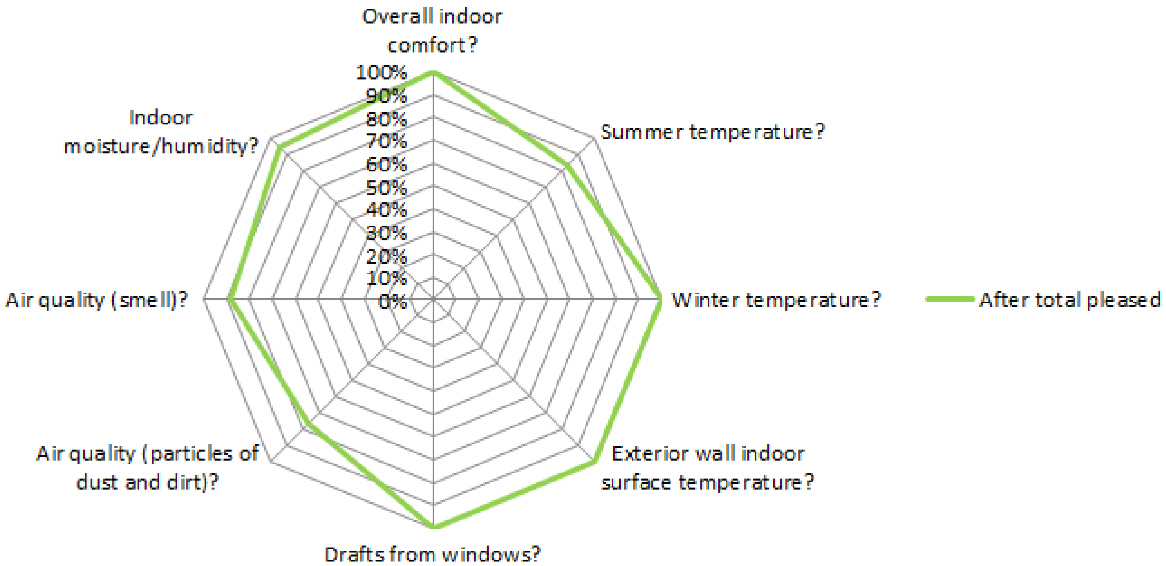


Figure 14: Evaluation of Well-being and health after retrofit, Munich.

3.4.3.2 Oulu - Tenants' Evaluation

In the Oulu demonstration the evaluation was carried out before and after the retrofit. Since the previous tenants were evicted prior to the retrofit, the pre-retrofit and post-retrofit conditions were not evaluated by the same tenants.

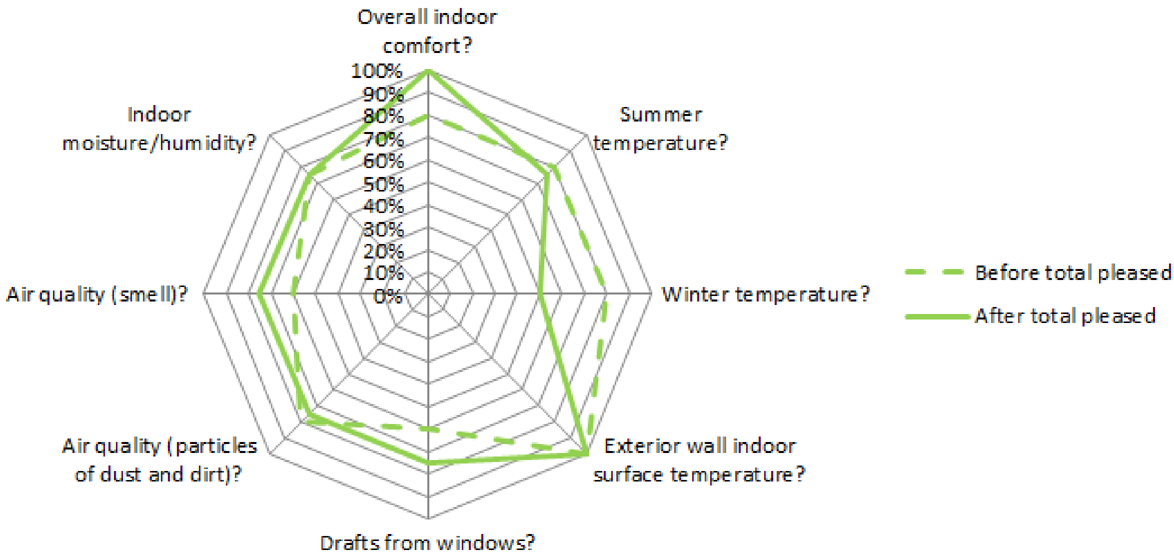


Figure 15: Evaluation of Well-being and health before and after retrofit, Oulu.

3.4.3.3 Voiron - Tenants' Evaluation

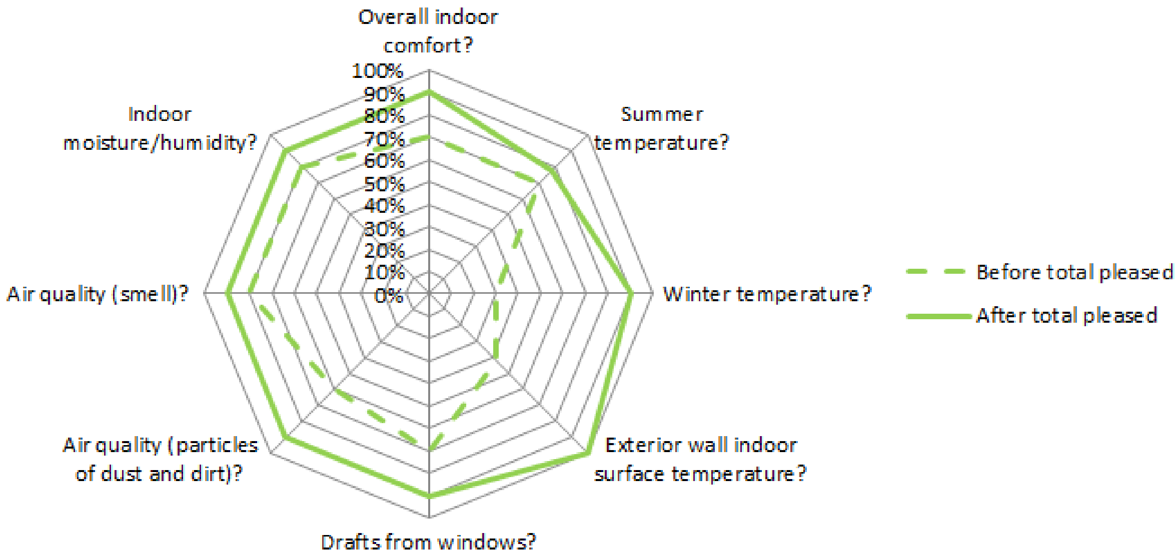


Figure 16: Evaluation of Well-being and health before and after retrofit, Voiron.

3.4.3.4 Augsburg - Tenants' Evaluation

The Augsburg demonstration showed a strong increase overall in all aspects concerning indoor comfort. In particular, the thermal comfort increased from a relatively low level to almost 100 % pleased after the retrofit. In Augsburg the balconies were converted into winter gardens and the fresh air intake goes through these which pre-heats the air to some extent, reducing the sensation of draft

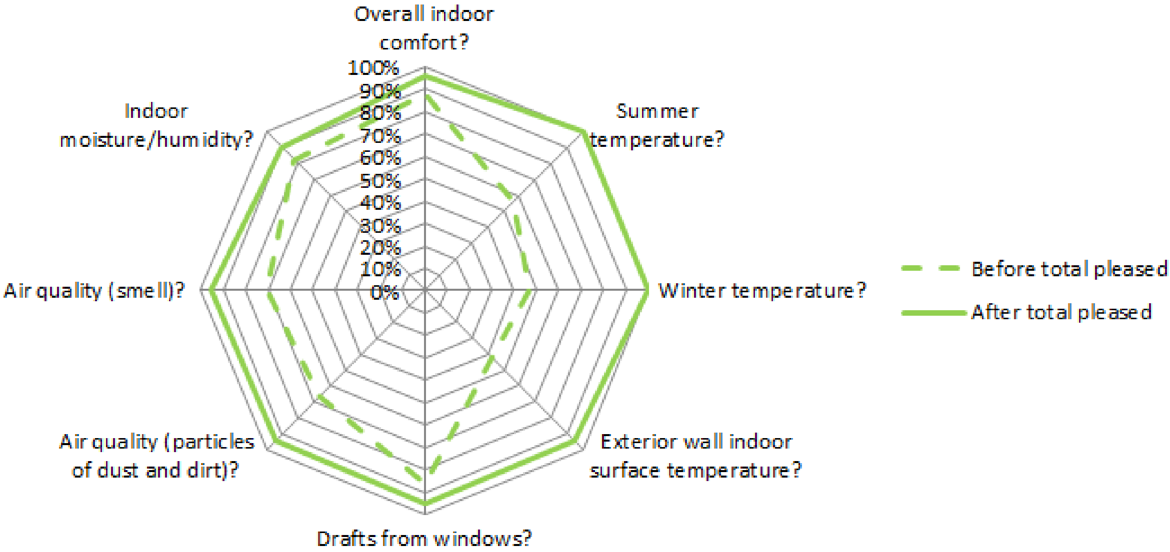


Figure 17: Evaluation of Well-being and health before and after retrofit, Augsburg.

3.4.3.5 Halmstad - Tenants' Evaluation

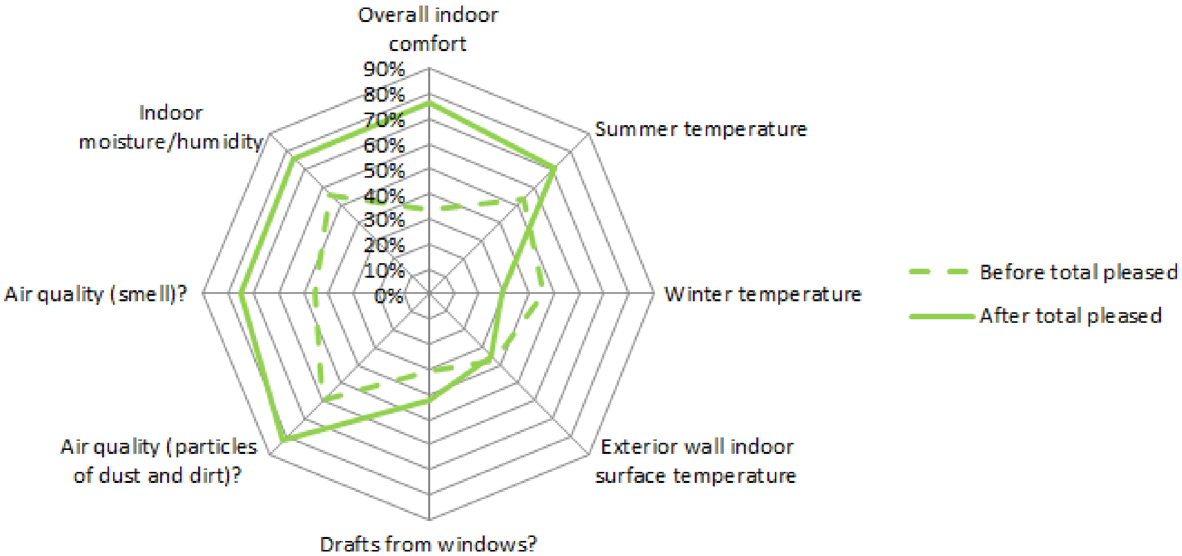


Figure 18: Evaluation of Well-being and health before and after retrofit, Halmstad.

3.4.3.6 Roosendaal - Tenants' Evaluation

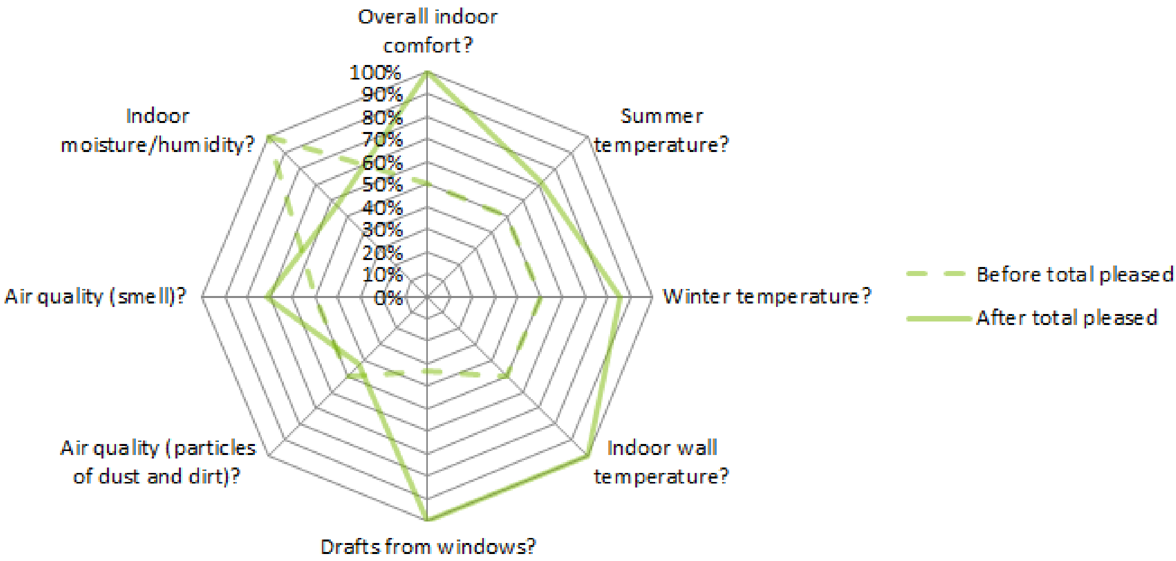


Figure 19: Evaluation of Well-being and health before and after retrofit, Roosendaal.

3.4.3.7 London - Tenants' Evaluation

No evaluation for the London demonstration was carried out within the timeframe of E2ReBuild.

3.4.4 Experiences from the Monitoring Programme – Focus on Tenants' Indoor Environment

Temperature is important to measure in order to keep track of the indoor environment in the building and apartments. In the summer it is usual that the temperature gets higher than comfortable, and in the winter the temperature can get too low if the heating system is not working properly or isn't well tuned. If the heating system is not well adjusted, it is also possible that the temperature gets too high even in the winter, especially if the tenants can't adjust the heating system by themselves. Another reason to measure the temperature could be to relate the temperature to the energy used for space heating. A low energy use for space heating is always desired, but should never be done at the expense of low comfort level (among other things low temperature).

The relative humidity (RH) is another parameter that can show if the ventilation isn't working as it should.

Temperature and relative humidity are quite easy to measure. Thus the chosen measurement point is important to get reliable and comparable data. If the temperature and RH are only measured in one room in the flat, the measuring point should be centrally placed. The measuring point should also be placed at an inner wall with no direct sun lightning. The meter should be installed at 1.1 meters height above the floor.

There are several types of suitable measurement equipment available to measure temperature and RH. The system can be either manually or wireless read. It is preferable that it is possible to read the equipment data without disturbing the tenants (e.g. with wireless connection).

Temperature and RH should be measured in a representative number of apartments in the building or houses, and include several rooms, such as living room, bedroom, kitchen. If possible the measurement should be done both before and after retrofitting. The temperature and RH should be logged with a frequency of at least one measuring point per hour.

Carbon dioxide produced by people can be used as a natural tracer gas for air change rate measurements and subsequently indirectly for determining the indoor air quality. Comparing the outdoor CO_2 concentration with the measured indoor gives an indication of the quality of the indoor air but does not directly correlate to TVOCs and other hazardous substances such as particles.

The method is commonly used as a surrogate indicator for indoor air quality and the method can be used for a particular E2ReBuild demonstration. If chosen, the method must be specified according to relevant standards and methods.

Within the E2ReBuild project all of the demonstrations, apart from the London demonstration which was not completed within the time frame of E2ReBuild, included monitoring of the indoor environment but the extent of parameters and numbers of monitored dwellings differ. Also, the time period for monitoring has varied between demonstrations and parameters making it difficult to directly compare them, but the results do present interesting findings to be compared to the end-user evaluation presented in the previous chapter.

3.4.4.1 Munich - Evaluation of Monitored Indoor Environment

The Munich demonstration provided data on temperatures and relative humidities over different periods and for a number of locations. However, all data was not coherent and some gaps exist and therefor the presented data covers only two apartments and the time period August 2012 until February 2013.

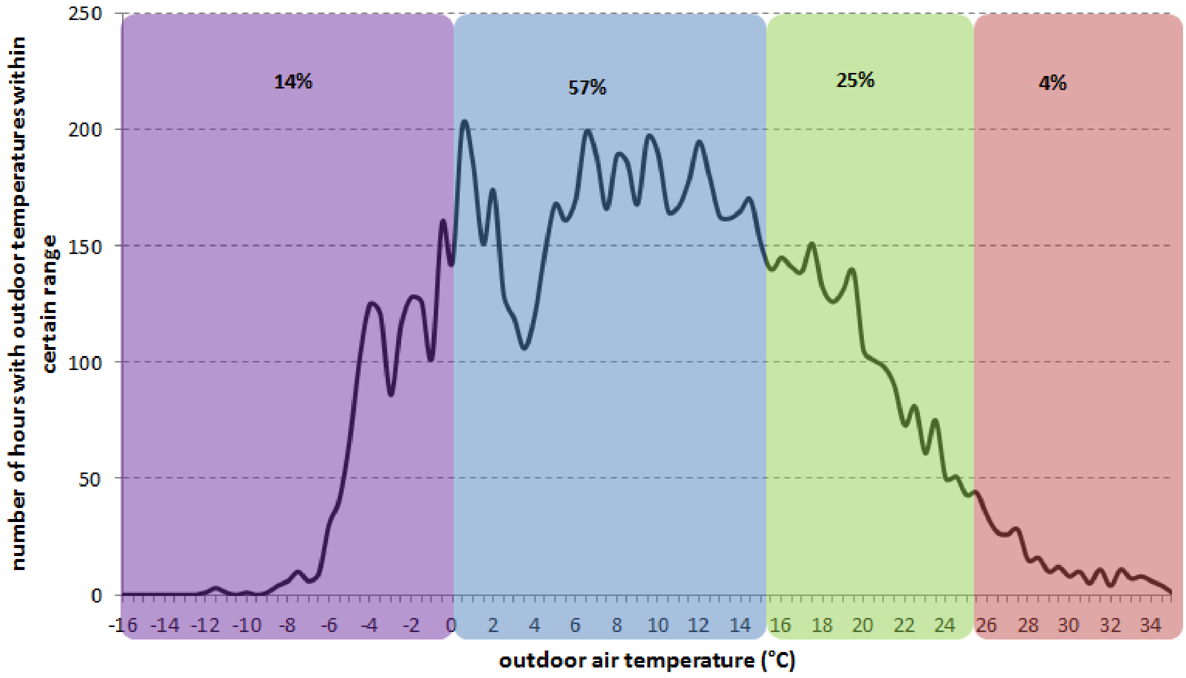


Figure 20: Munich outdoor temperature distribution over the monitored period, August 2012 - February 2013.

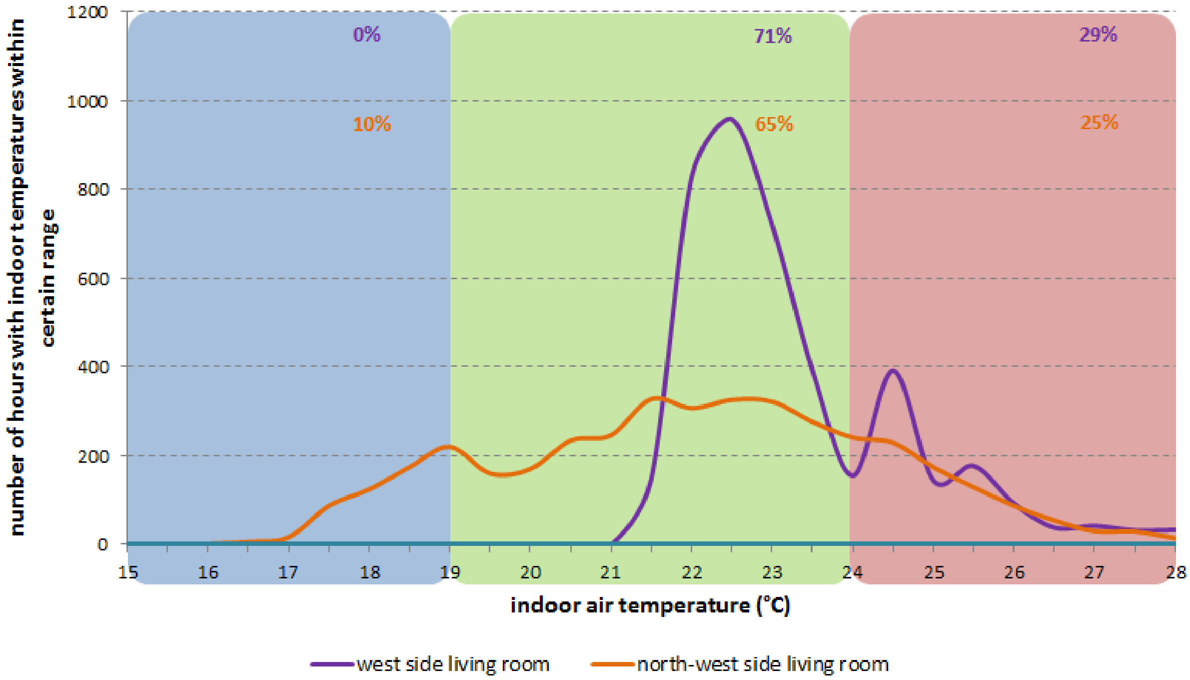


Figure 21: Munich indoor air temperature distribution for two apartments during the monitoring period, August 2012 - February 2013.

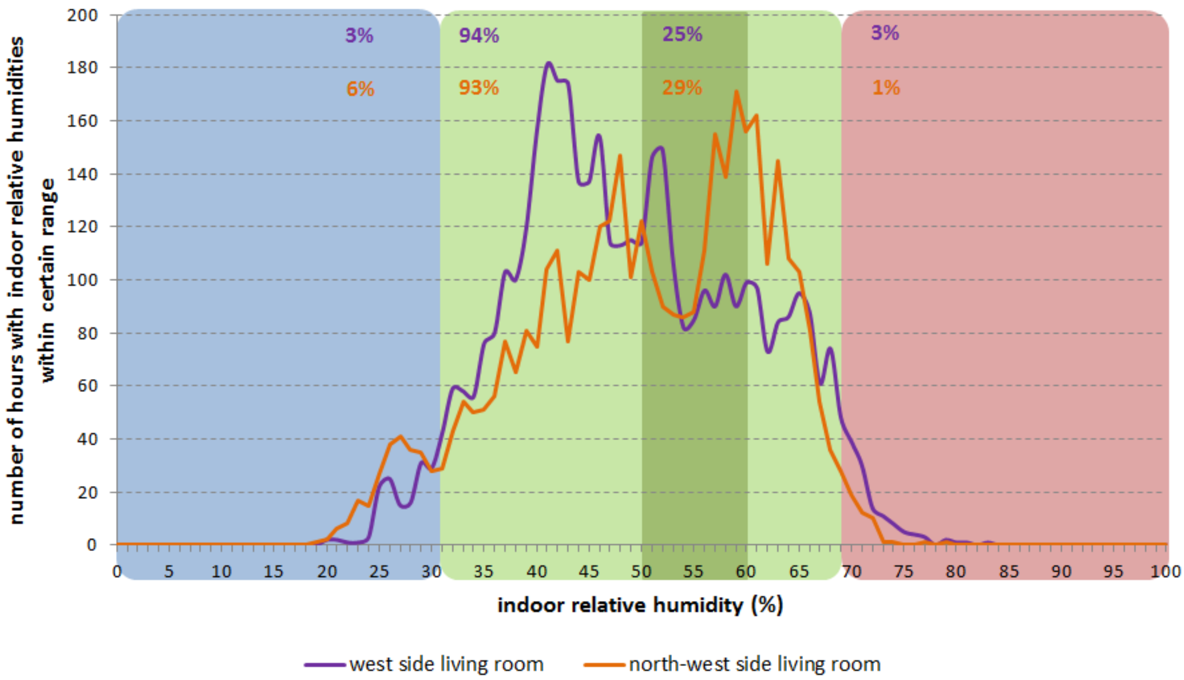


Figure 22: Distribution of indoor relative humidities over the monitored period, August 2012 - February 2013, for two apartments in the Munich demonstration. The indicated percentages of time between the optimum 50-60% relative humidity are also included in the percentages shown for 30-70% relative humidity which indicates an acceptable range of humidity.

3.4.4.2 Oulu - Evaluation of Monitored Indoor Environment

In Oulu the indoor temperatures and relative humidities were continuously monitored. In the below figures the outdoor temperature distribution over the time period of March until November 2013 are presented along with the corresponding results from one apartment, showing the distribution for three different rooms, the south facing kitchen / living room, and two north facing bedrooms.

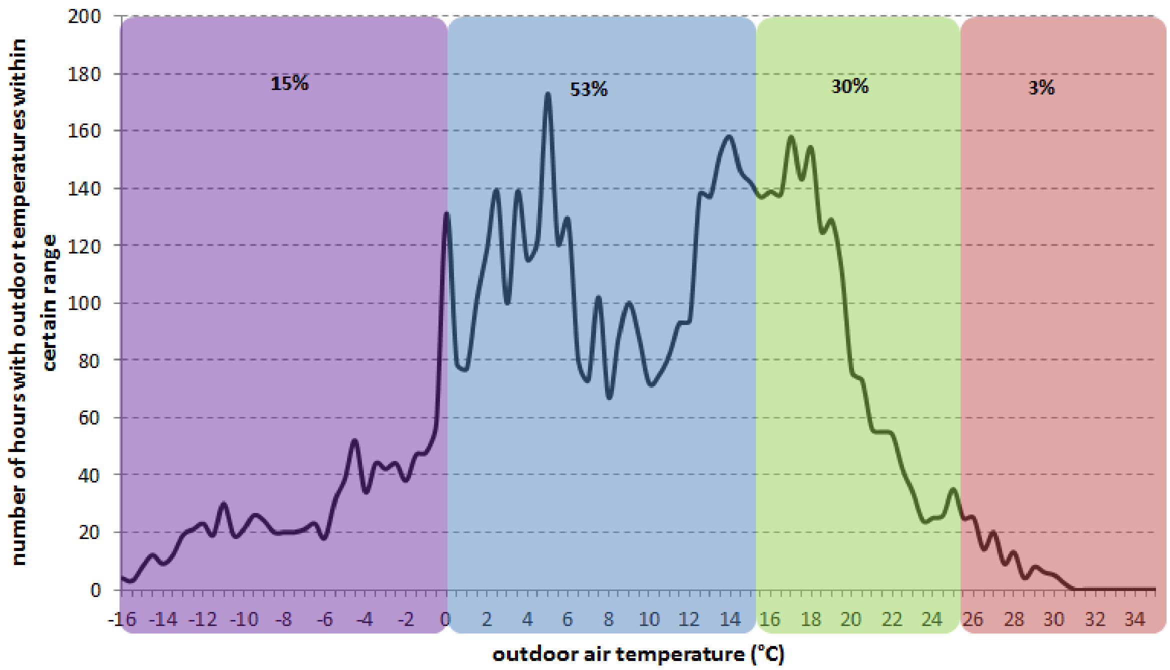


Figure 23: Oulu outdoor temperature distribution over the monitored period, March - November 2013.

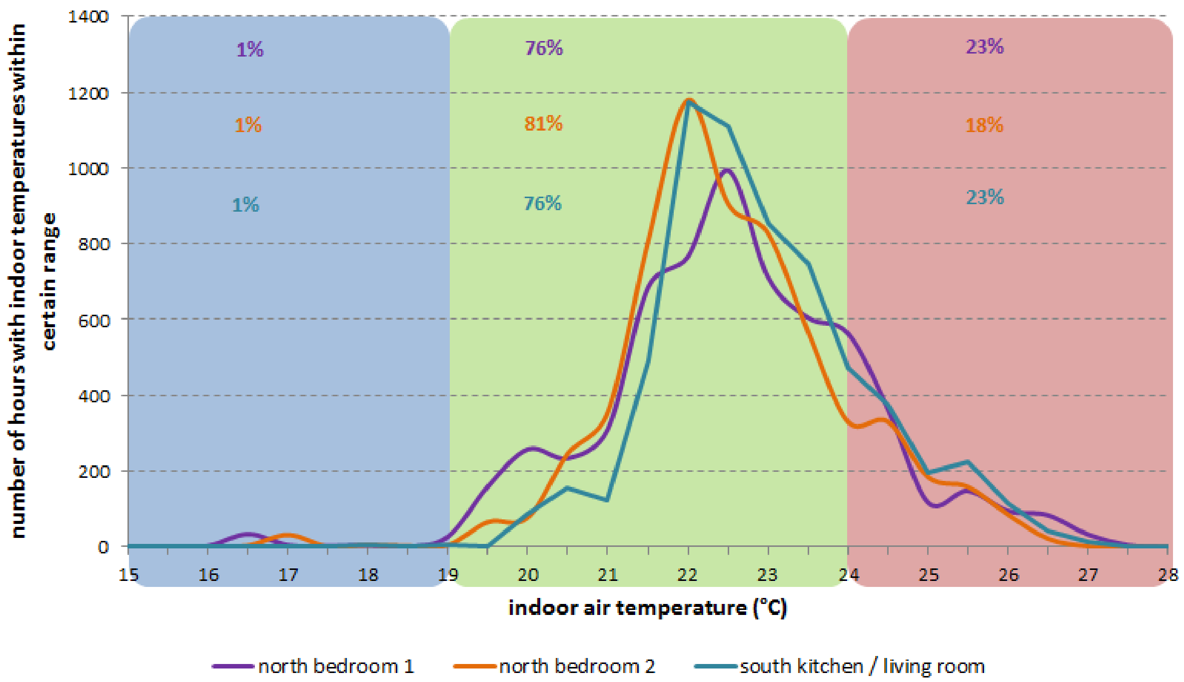


Figure 24: Oulu indoor air temperature distribution for one apartment during the monitoring period, March - November 2013.

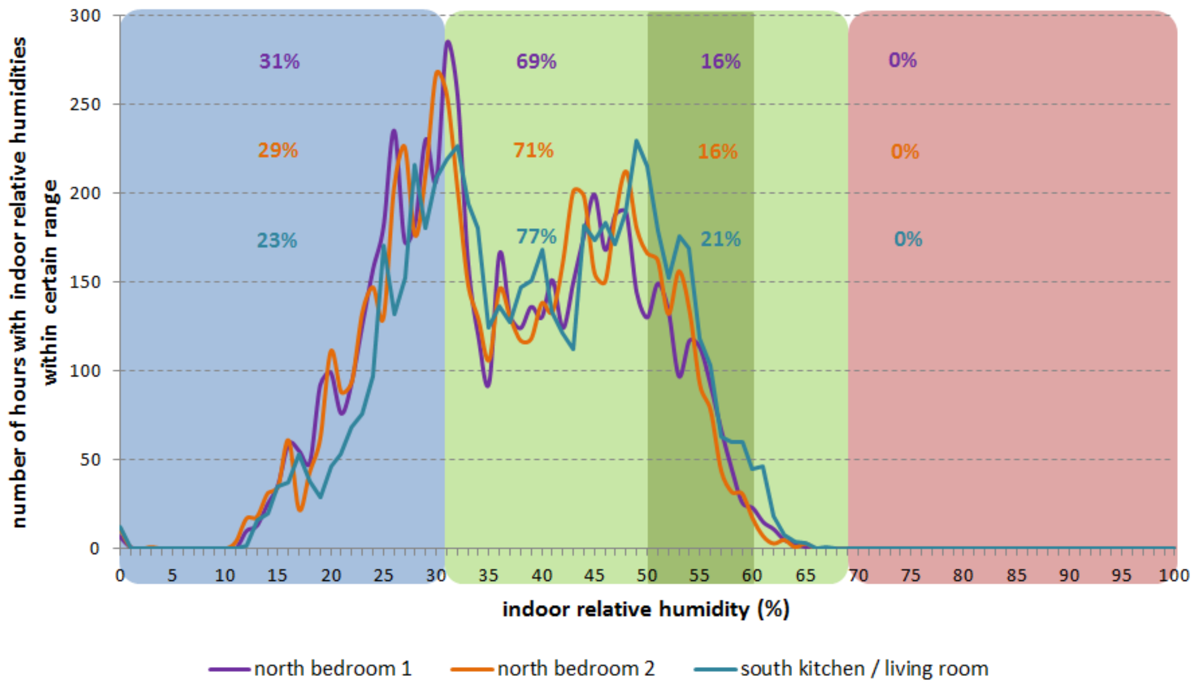


Figure 25: Distribution of indoor relative humidities over the monitored period, August 2012 - February 2013, for one apartment in the Oulu demonstration.

3.4.4.3 Voiron - Evaluation of Monitored Indoor Environment

In Voiron the outdoor and indoor temperatures were monitored for two shorter periods, in summer and winter.

The summer period is presented in Figure 26 and Figure 27 and the winter period in Figure 28.

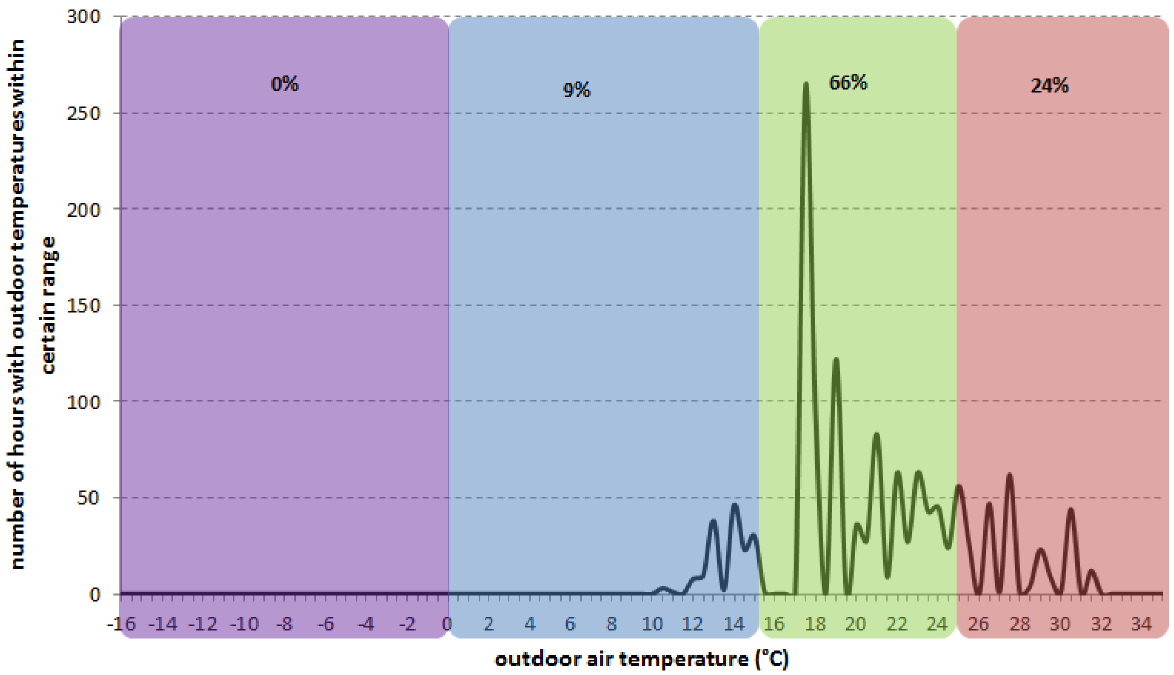


Figure 26: Voiron outdoor temperature distribution over the monitored period, July - September 2013.

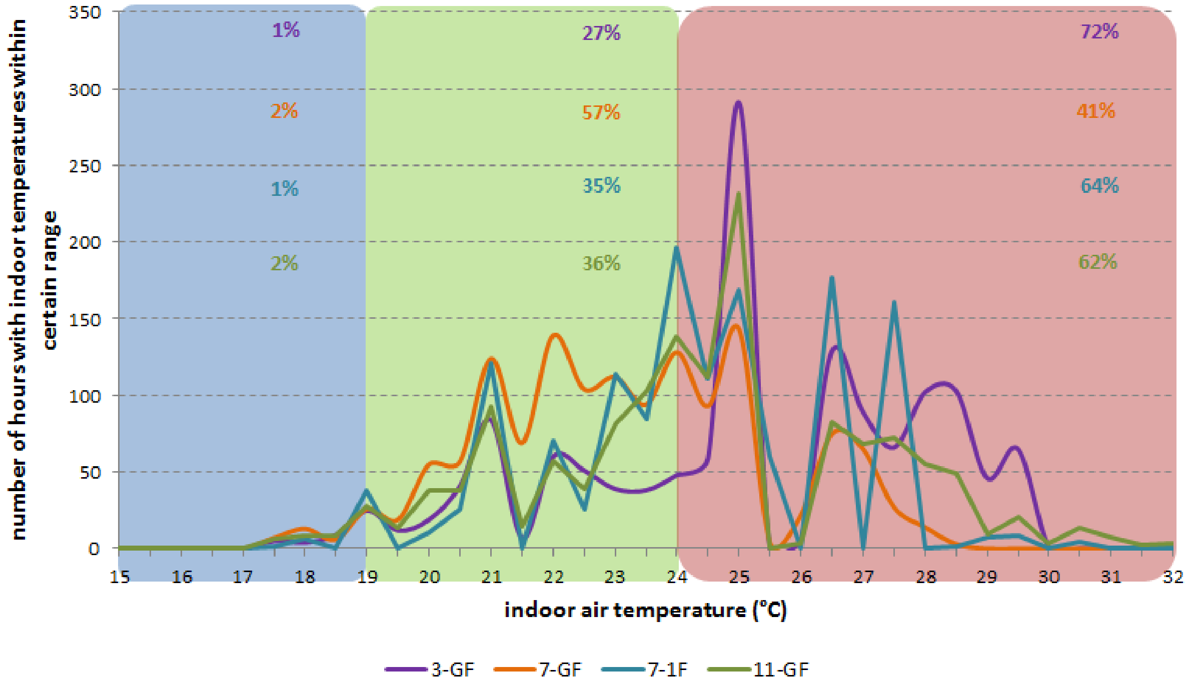


Figure 27: Voiron indoor summer temperature distribution for four apartments over the same time period. Apartments with numbers ending with GF indicates ground floor. 1F indicates first floor above ground floor.

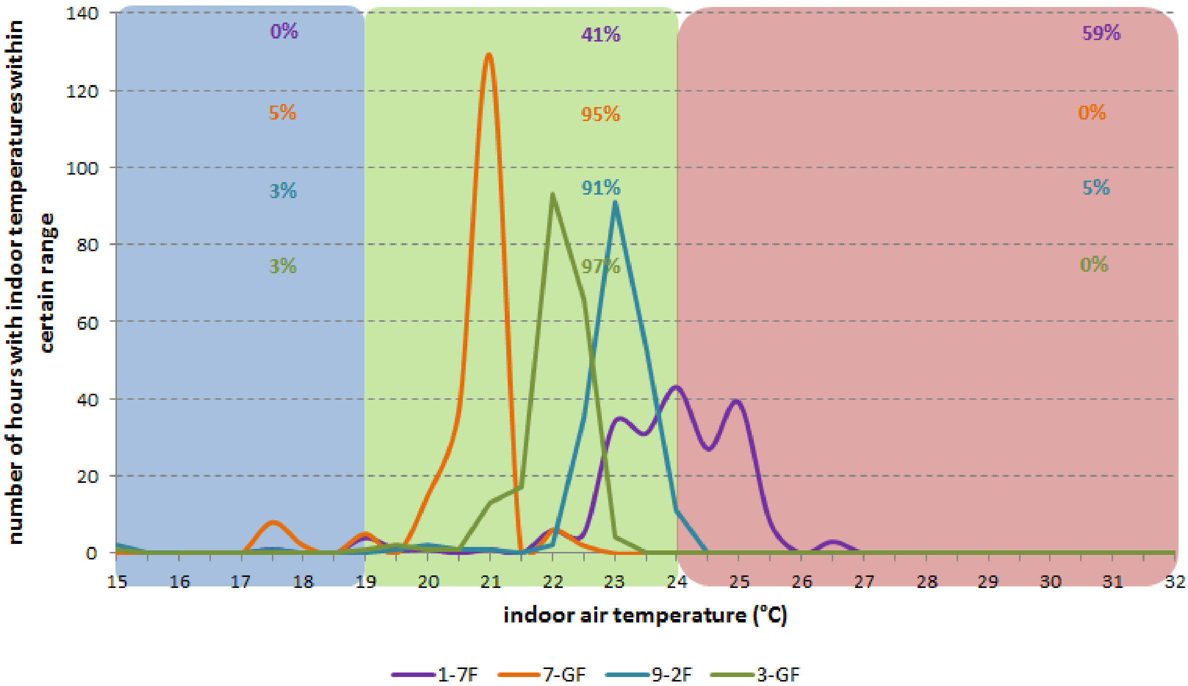


Figure 28: Voiron indoor winter temperature distribution for four apartments over one week in December 2013. Apartments with numbers ending with GF indicates ground floor. 1F indicates first floor above ground floor, etc.

3.4.4.4 Augsburg - Evaluation of Monitored Indoor Environment

In Augsburg the indoor temperatures, relative humidities and CO_2 levels were monitored over several periods but with missing data for certain times, in particular for the outdoor climate. Also, since the apartments were equipped with winter gardens from which ventilation air was supplied, the winter gardens were also monitored.

In the figures below the indoor conditions are presented but also the correlation between air temperatures in winter gardens and apartments air temperatures. Figure 29 below shows the outdoor temperature distribution over the time period of May until July 2013.

This can then be compared with the monitored air temperature distributions for three winter gardens on three different floors, Figure 30, and combined in Figure 32. Interesting to note is the distribution of temperatures depending on floor level. The lower floor, 1st floor, shows a temperature distribution with lower temperatures compared with the upper floors. This could be caused by e.g. shading from surrounding trees or different airing habits of the tenants. The winter gardens were also monitored for a longer time period, July 2012 – June 2013, Figure 31 and Figure 33. Here the same trend can be seen as for the short summer period, but also surprisingly high temperatures throughout the year, with minimum temperatures reaching much higher than the outdoor temperatures in winter. One reason for this can again be airing habits by the apartment's tenants, letting out warm air escape into the winter gardens.

In Figure 34 the indoor air temperature of one apartment on the fourth floor is compared to the corresponding winter garden air temperatures during winter.

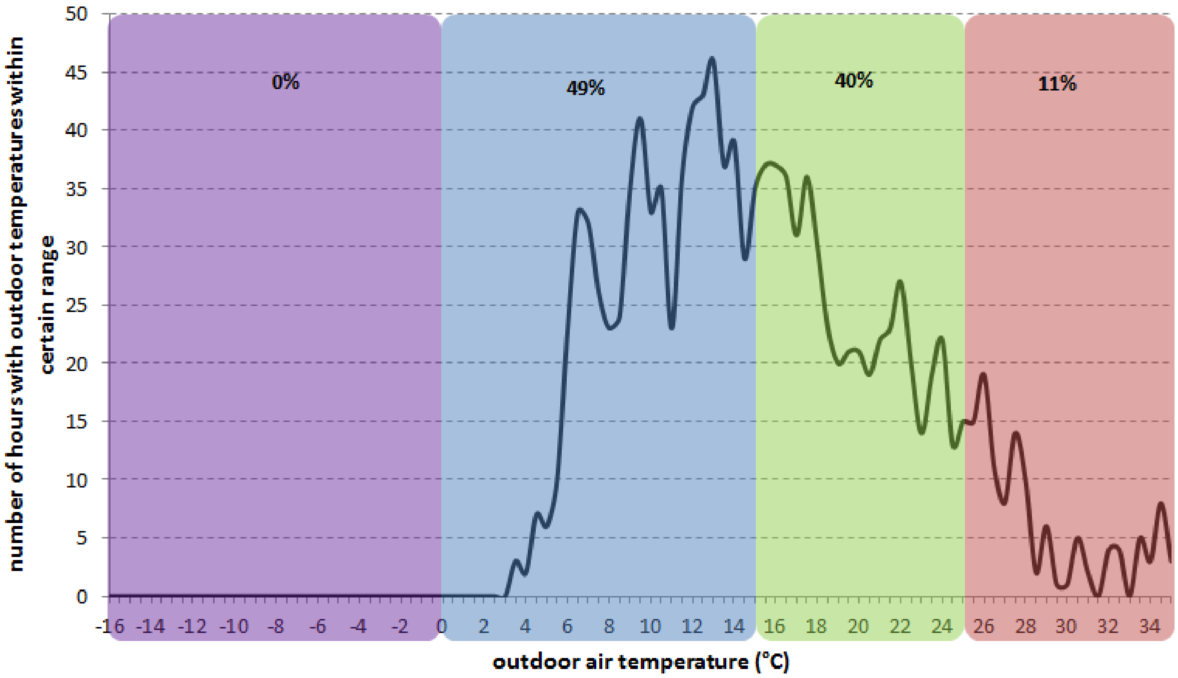


Figure 29: Outdoor temperature distribution for Augsburg over the time period of May – July 2013.

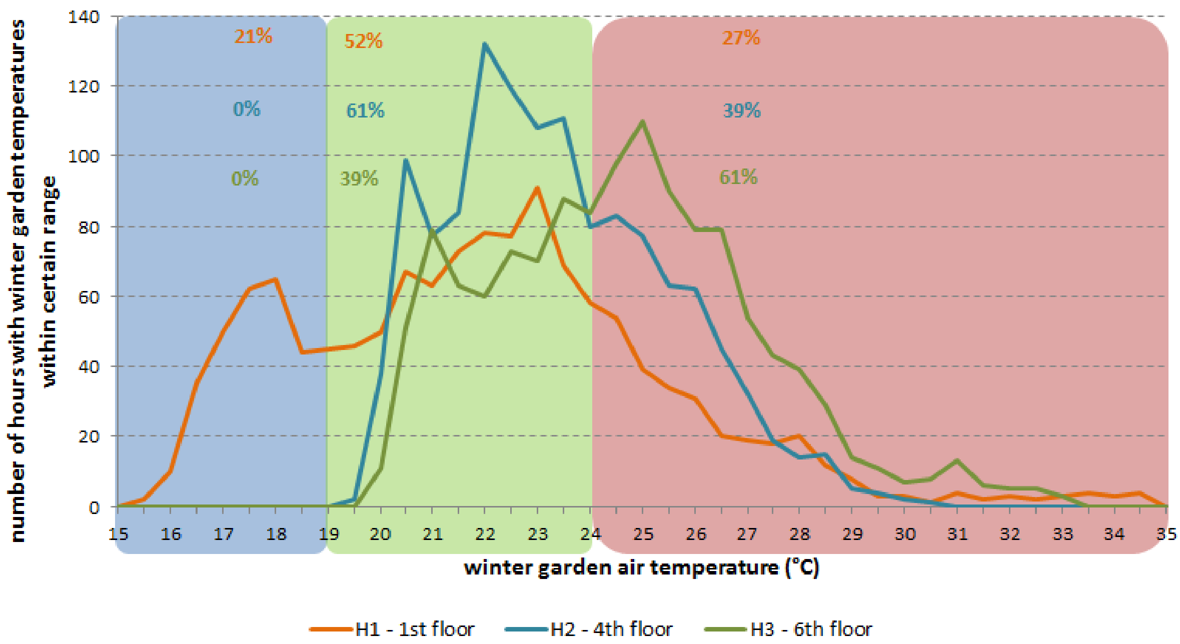


Figure 30: Augsburg winter gardens air temperature distribution over the time period of May – July 2013.

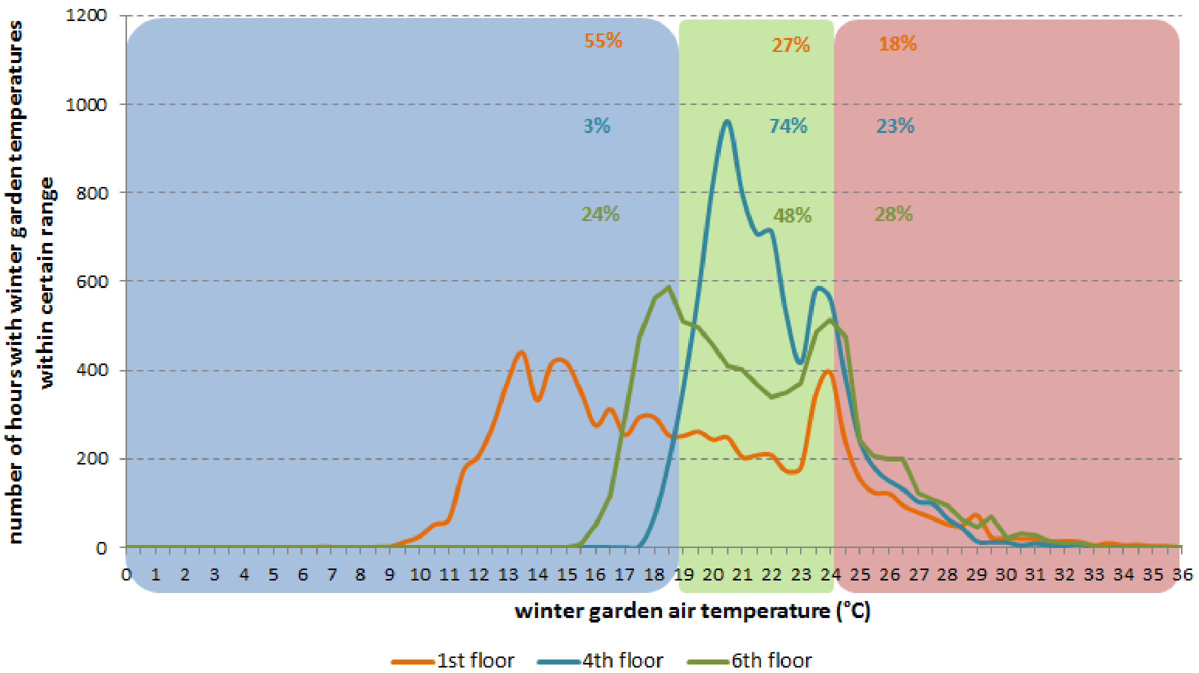


Figure 31: Augsburg winter gardens air temperature distribution over the time period of July 2012 – June 2013.

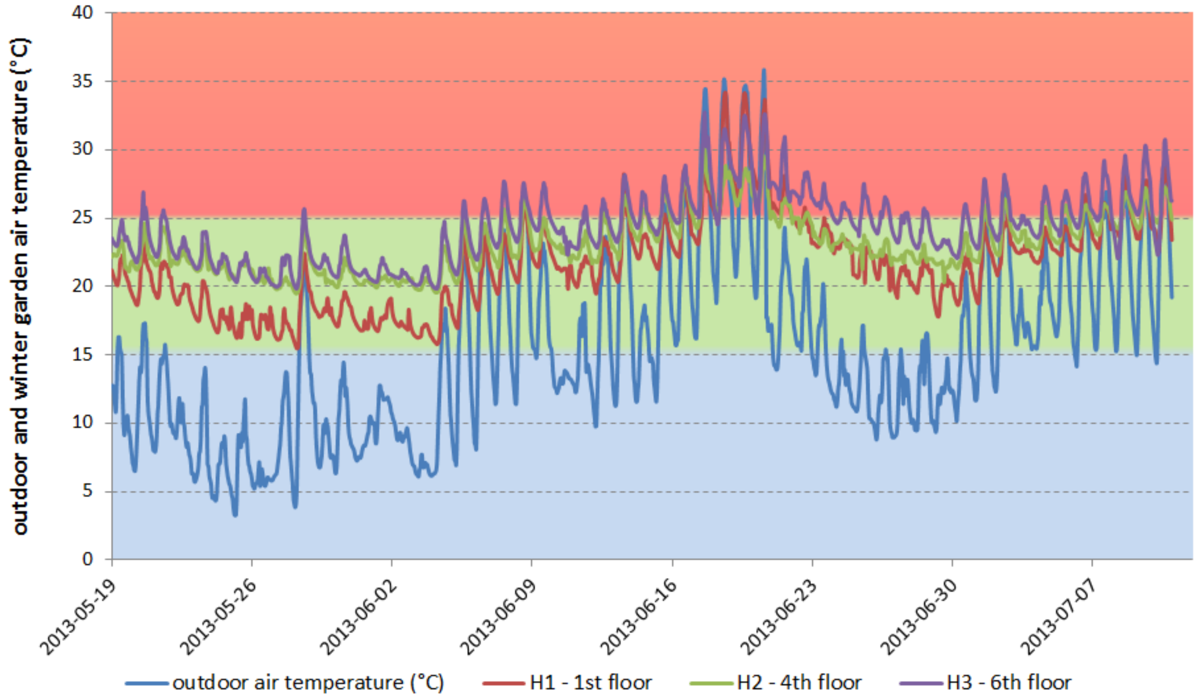


Figure 32: Augsburg winter gardens air temperature distribution over the time period of July 2012 – June 2013 compared to the outdoor air temperature.

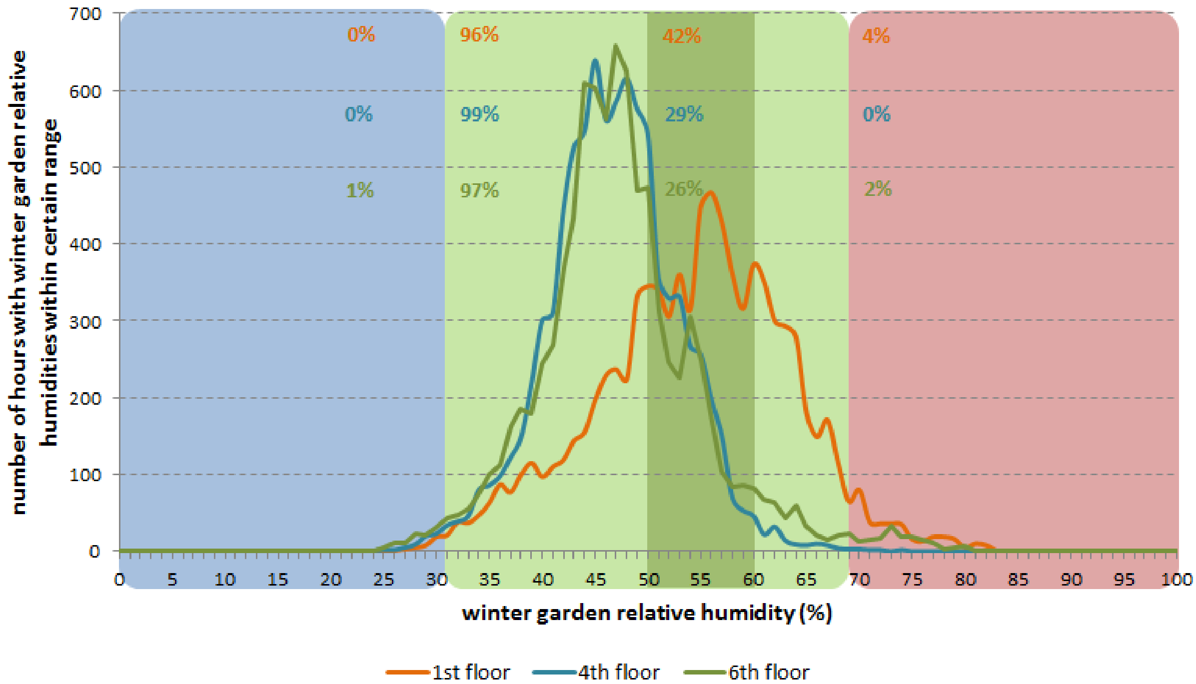


Figure 33: Augsburg winter gardens relative humidities distribution over the time period of July 2012 – June 2013.

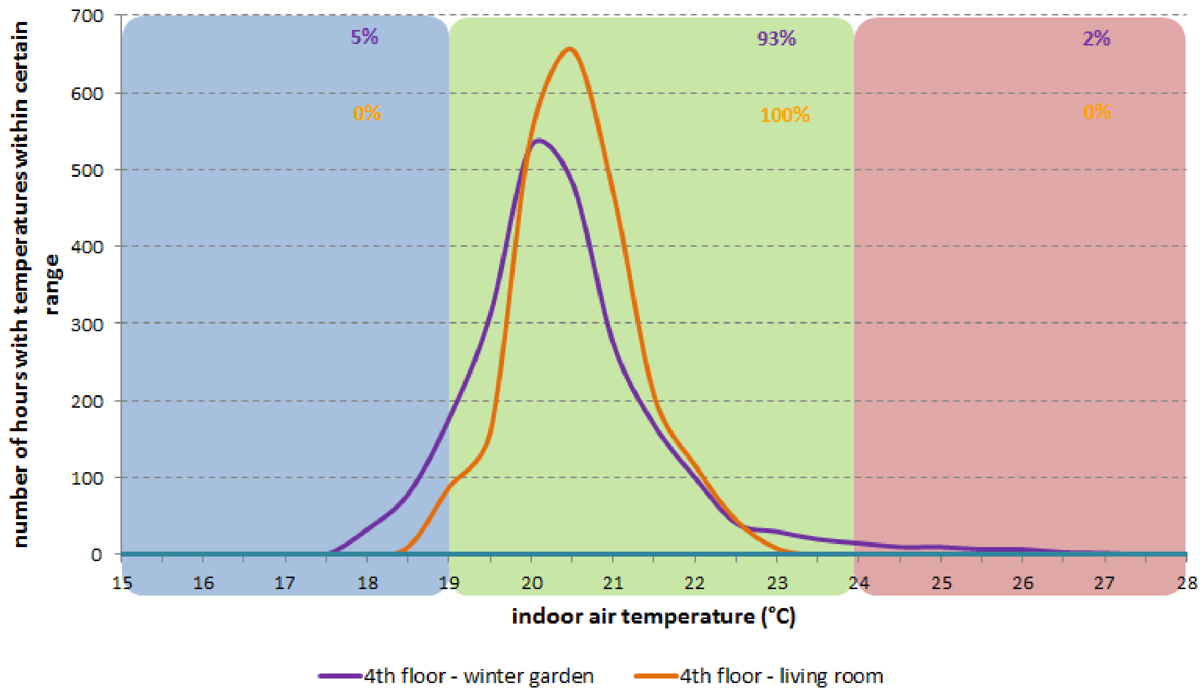


Figure 34: Comparison of indoor and winter garden air temperature distribution for one apartment in the Augsburg demonstration, November 2012 – February 2013.

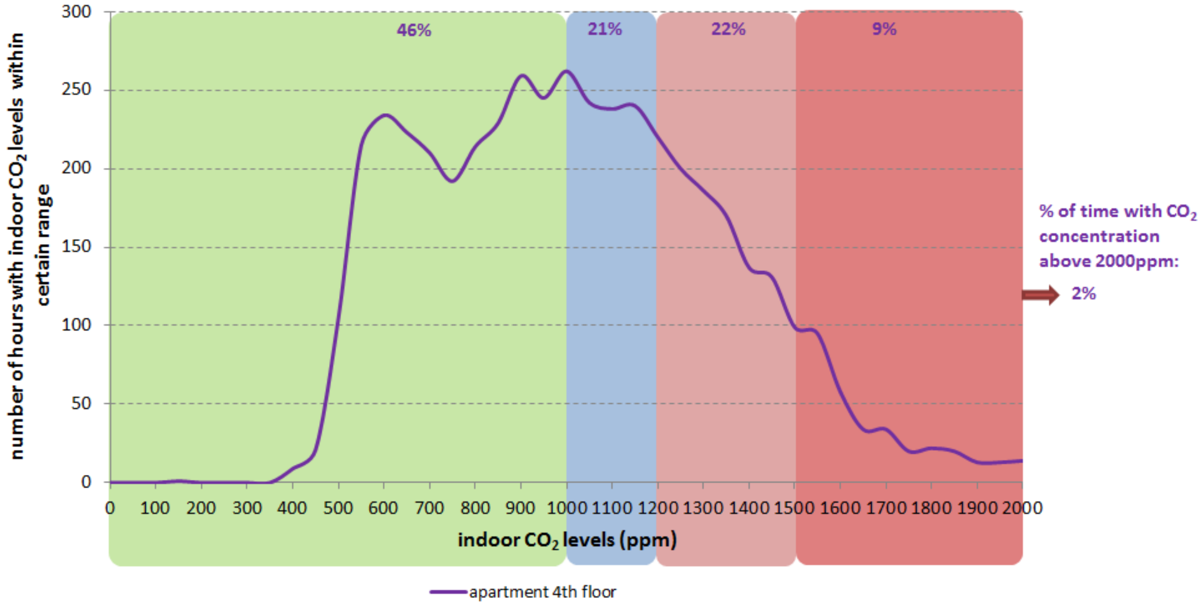


Figure 35: CO2 levels distribution for one apartment on the 4th floor during the monitored periods of November 2012 – February 2013, July – August 2013 and October – December 2013.

3.4.4.5 Halmstad - Evaluation of Monitored Indoor Environment

In Halmstad the indoor temperatures were monitored from December 2012 until August 2013. Several apartments over different floors were monitored. The intention was to monitor for a full year, however, due to difficulties in data storage some early data was lost. The outdoor air temperatures were monitored for a full year.

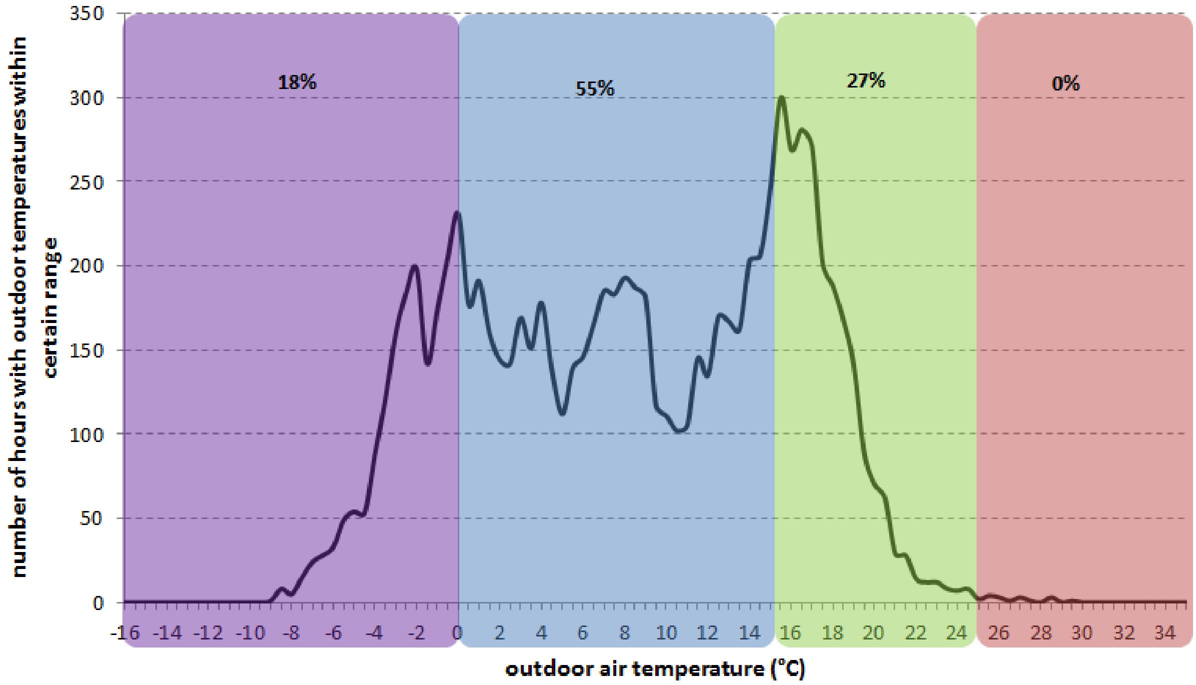


Figure 36: Halmstad outdoor air temperature distribution, July 2012 – July 2013.

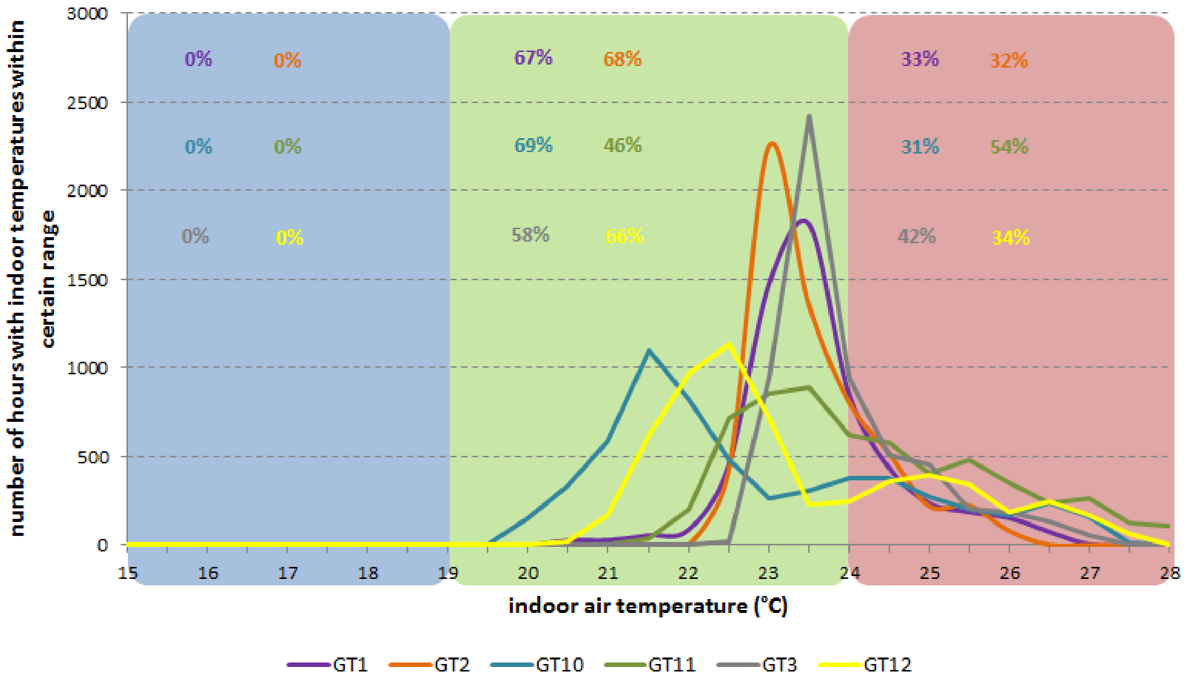


Figure 37: Halmstad indoor air temperature distribution in six apartments, floors 2 and 3. GT1, 2, 10 and 11 are located on the 2nd floor, GT 3 and 12 are on the 3rd floor.

Figure 38: Example of sensor locations for the Halmstad demonstration.

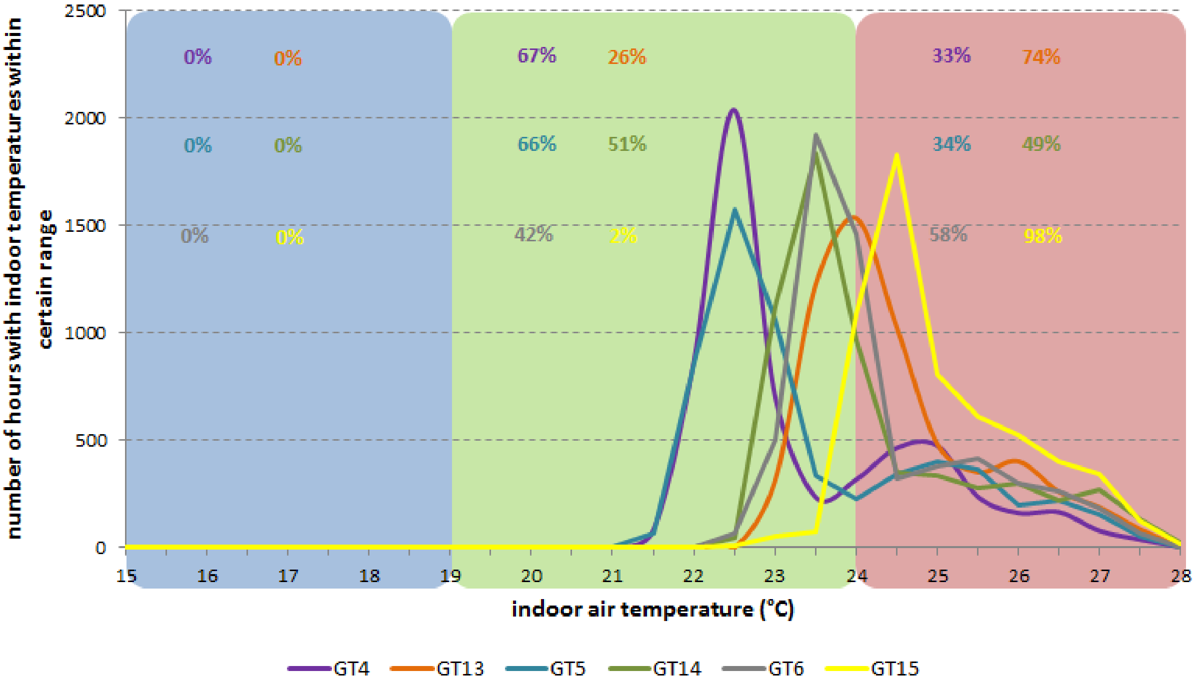


Figure 39: Halmstad indoor air temperature distribution in six apartments, floors 4 to 6. GT4 and 13 are located on the 4th floor, GT 5 and 14 are on the 5th floor and GT6 and 15 are on the 6th floor.

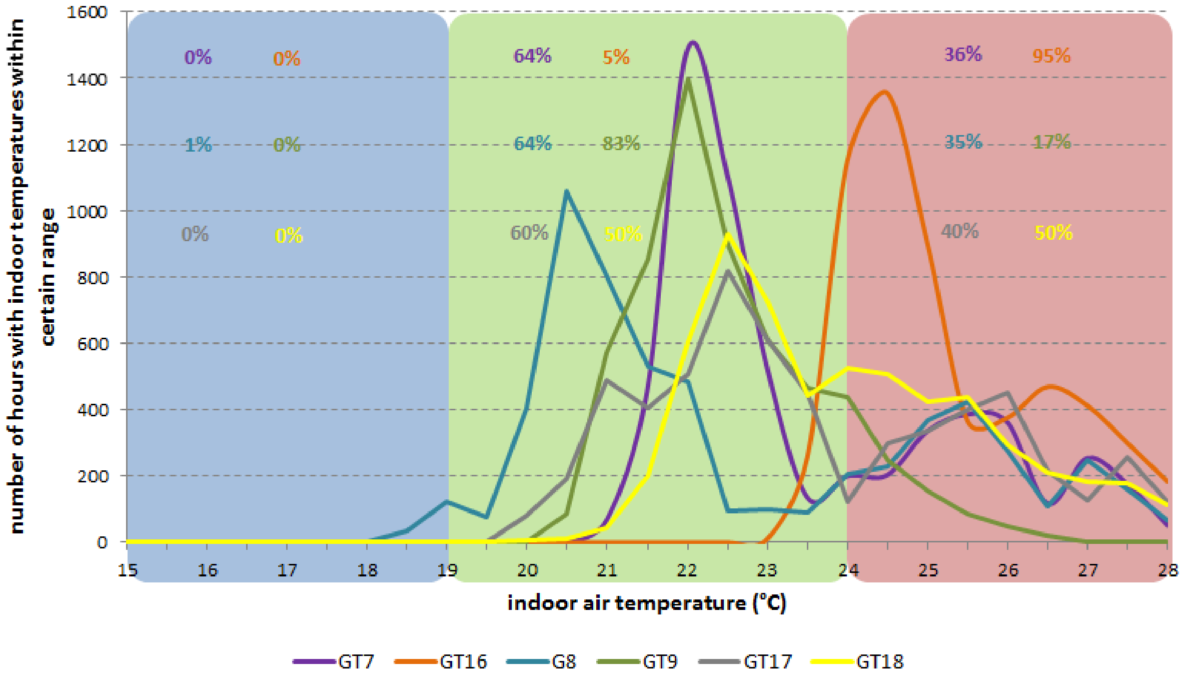


Figure 40: Halmstad indoor air temperature distribution in six apartments, floors 7 and 8. GT7 and 16 are on the 7th floor, GT8, 9, 17 and 18 are located on the 8th floor.

3.4.4.6 Roosendaal - Evaluation of Monitored Indoor Environment

The Roosendaal demonstration provided a full monitoring period of one year for 5 houses. Parameters included outdoor and indoor air temperatures, relative humidities and CO_2 levels. Airing habits was also monitored with sensors detecting opened and closed windows. The findings from this study are presented in Chapter 3.5.3, Airing habits. The row house dwellings were monitored in the living room on the ground floor and both bedrooms on the second floor.

3.4.4.6.1 Roosendaal House H0100

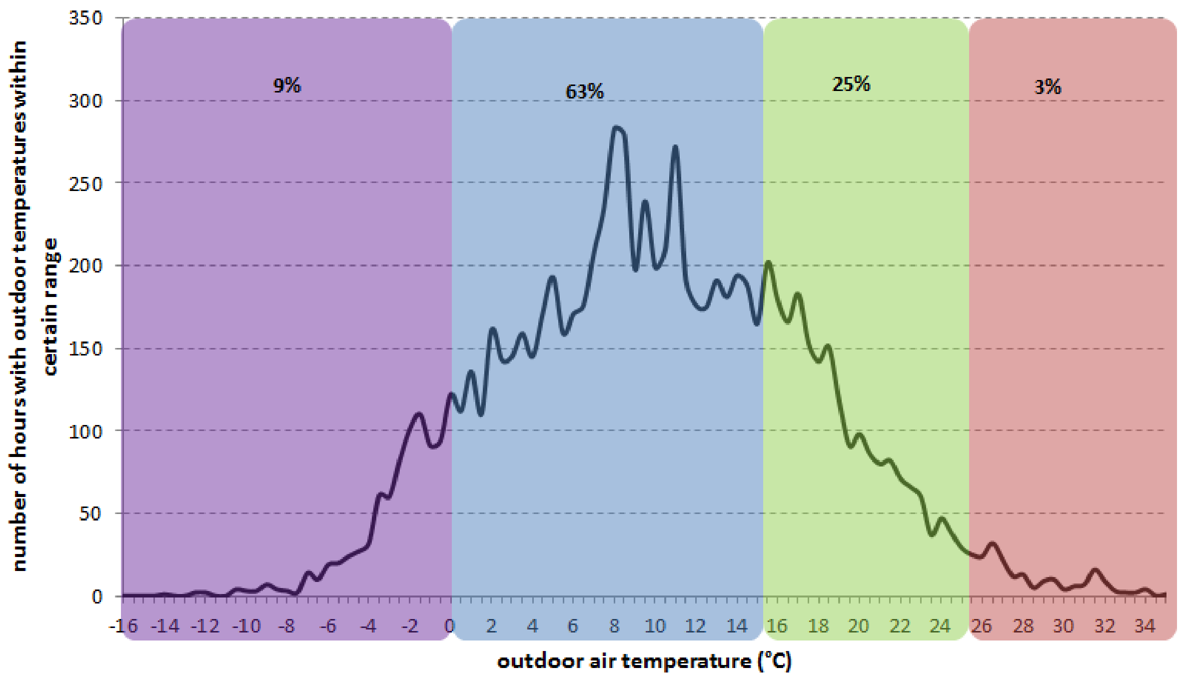


Figure 41: Outdoor air temperature distribution during 2013 for Gilze Rijen (close to Roosendaal).

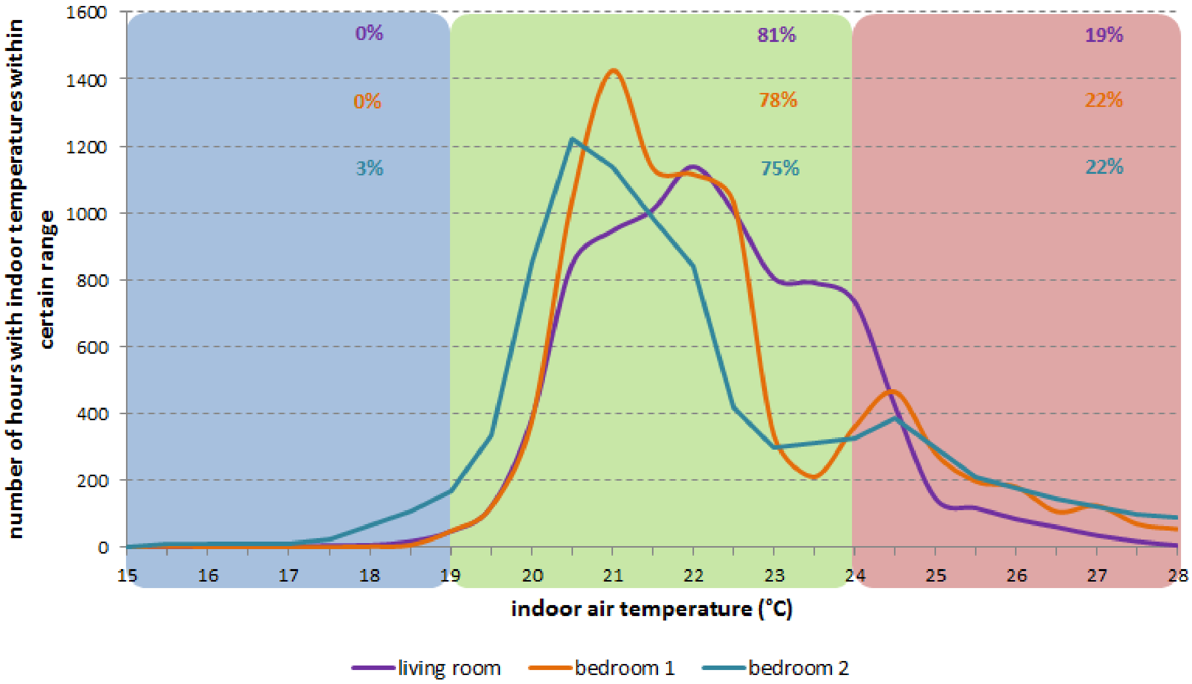


Figure 42: Roosendaal house H0100, distribution of indoor air temperatures for 2013.

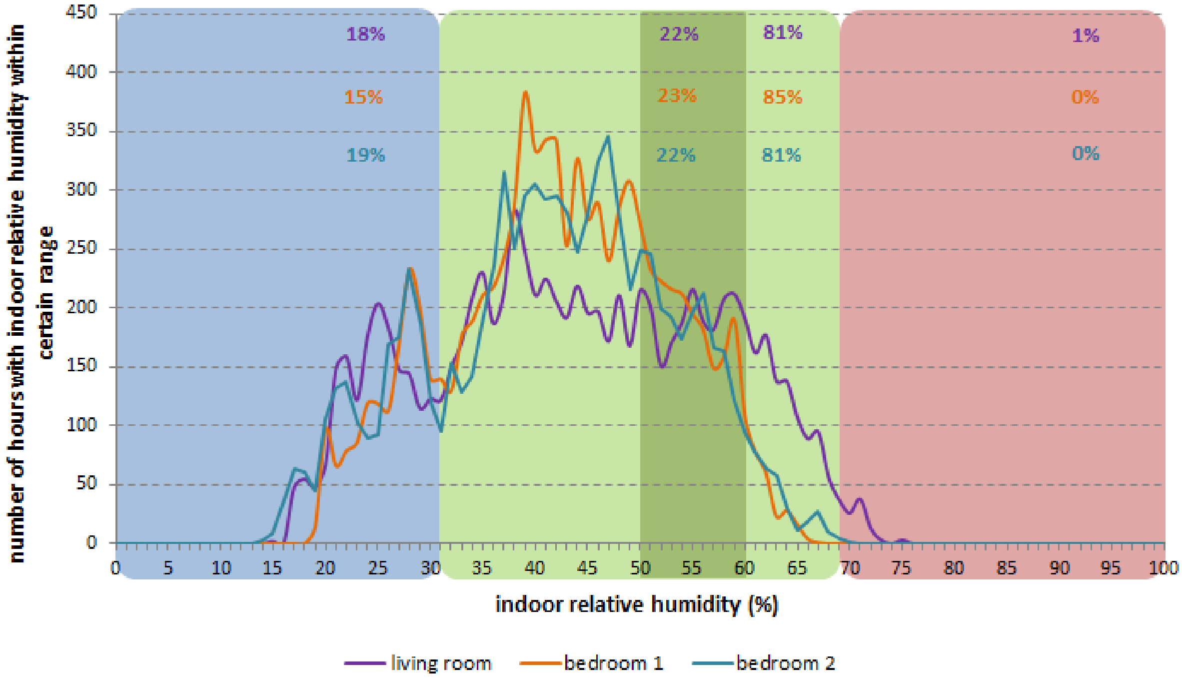


Figure 43: Roosendaal house H0100, distribution of indoor relative humidities for 2013.

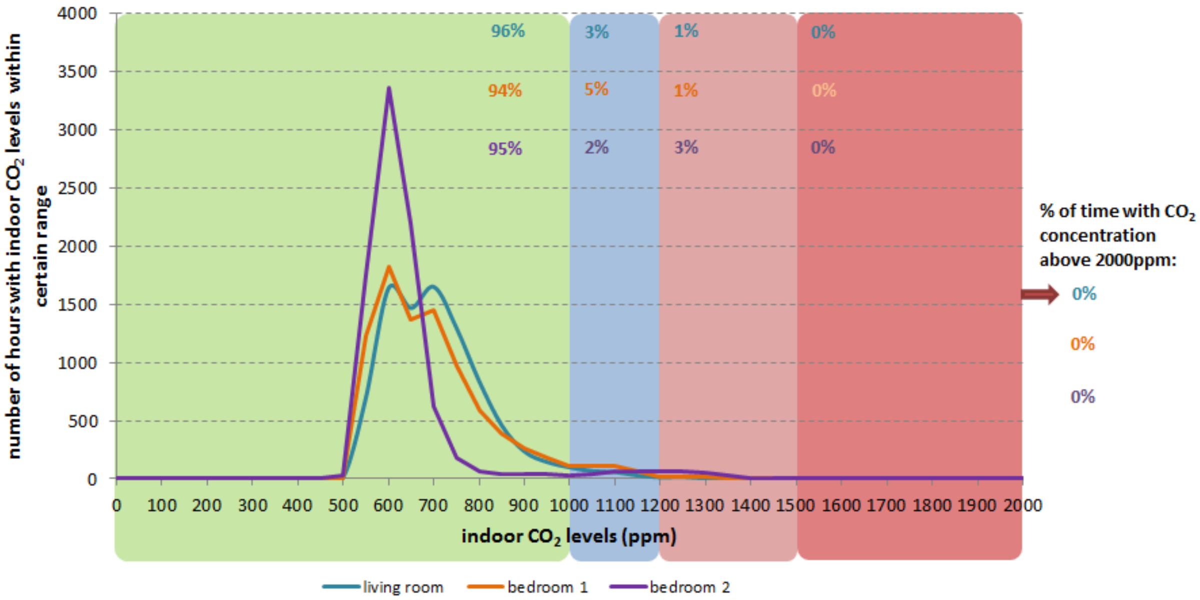


Figure 44: Roosendaal house H0100, distribution of indoor CO_2 levels for 2013.

3.4.4.6.2 Roosendaal House H0200

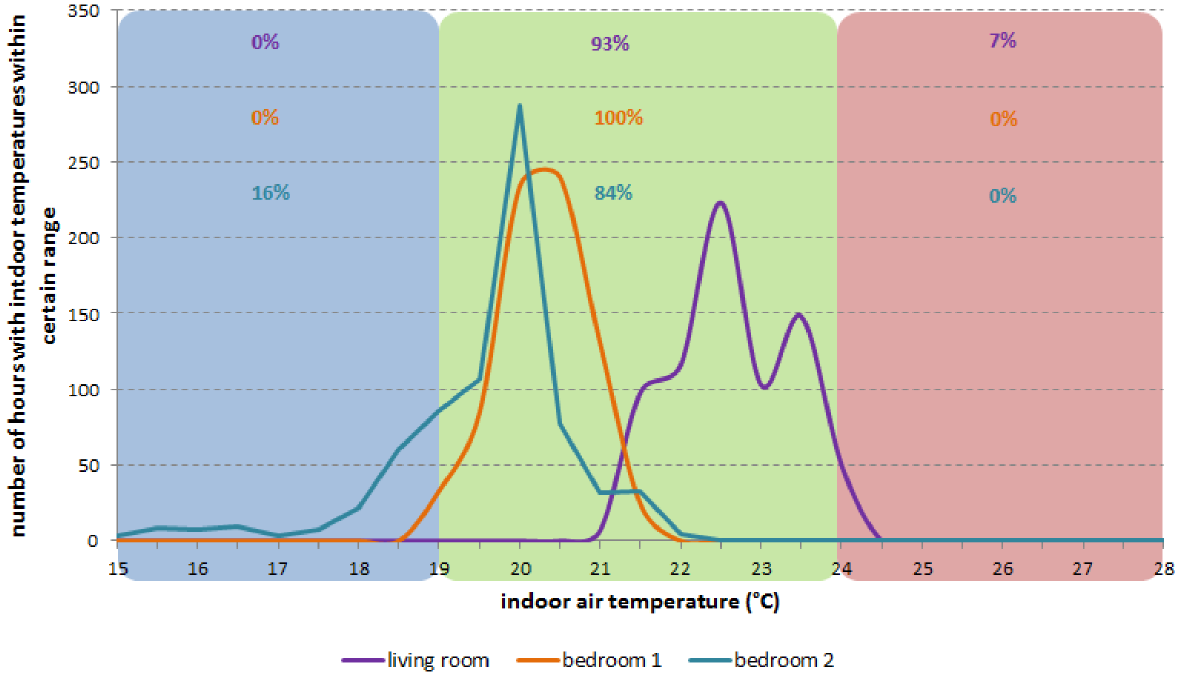


Figure 45: Roosendaal house H0200, distribution of indoor air temperatures for 2013.

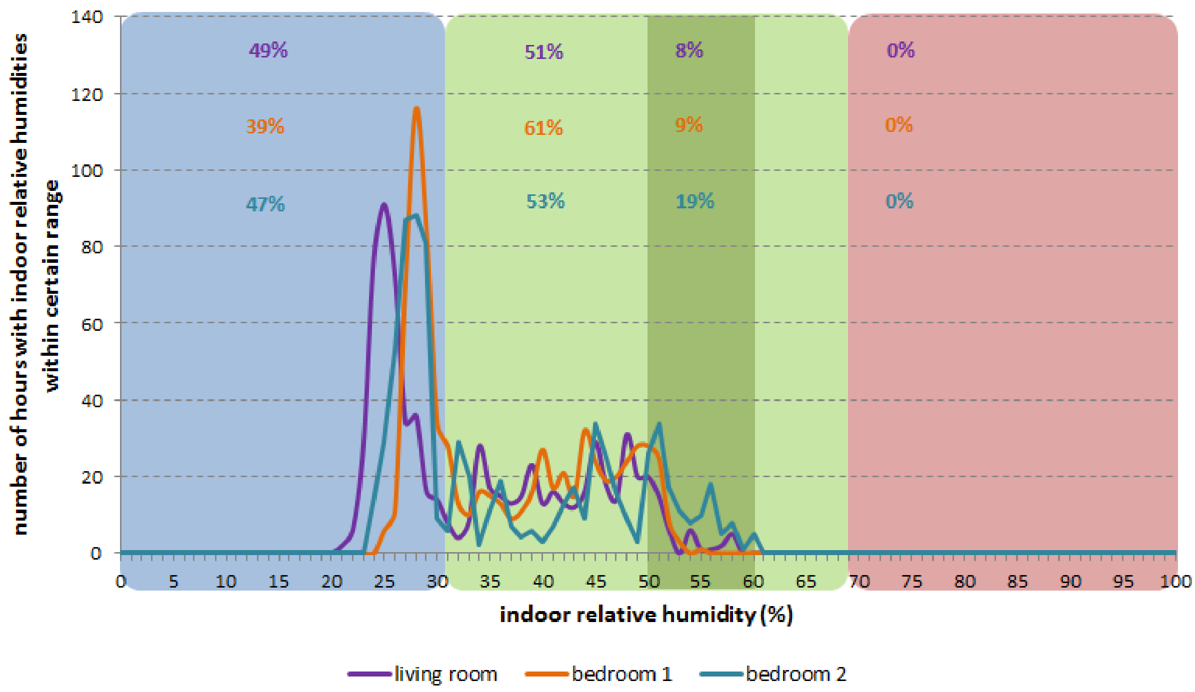


Figure 46: Roosendaal house H0200, distribution of indoor relative humidities for 2013.

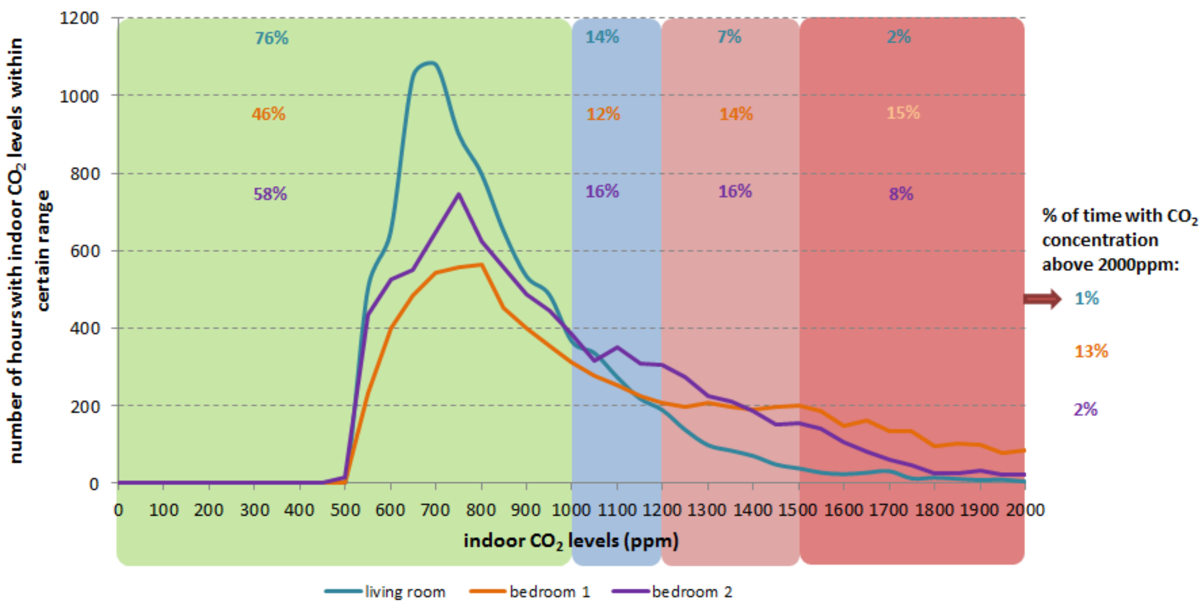


Figure 47: Roosendaal house H0200, distribution of indoor CO2 levels for 2013.

3.4.4.6.3 Roosendaal House H0400

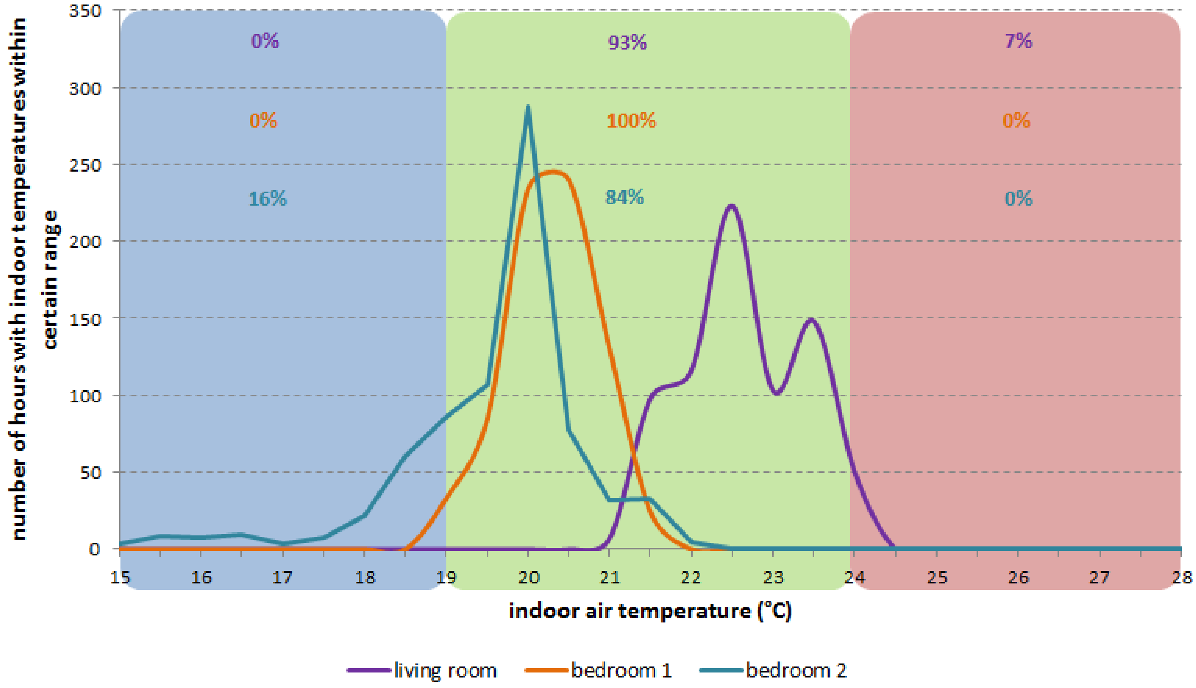


Figure 48: Roosendaal house H0400, distribution of indoor air temperatures for 2013.

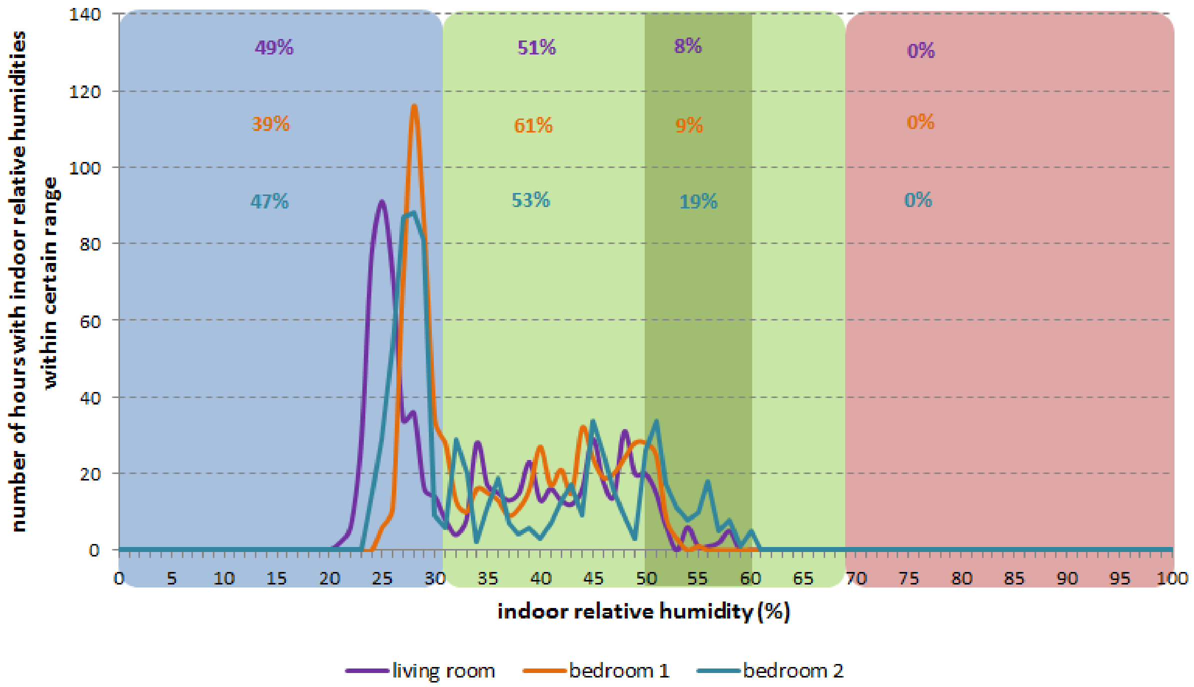


Figure 49: Roosendaal house H0400, distribution of indoor relative humidities for 2013.

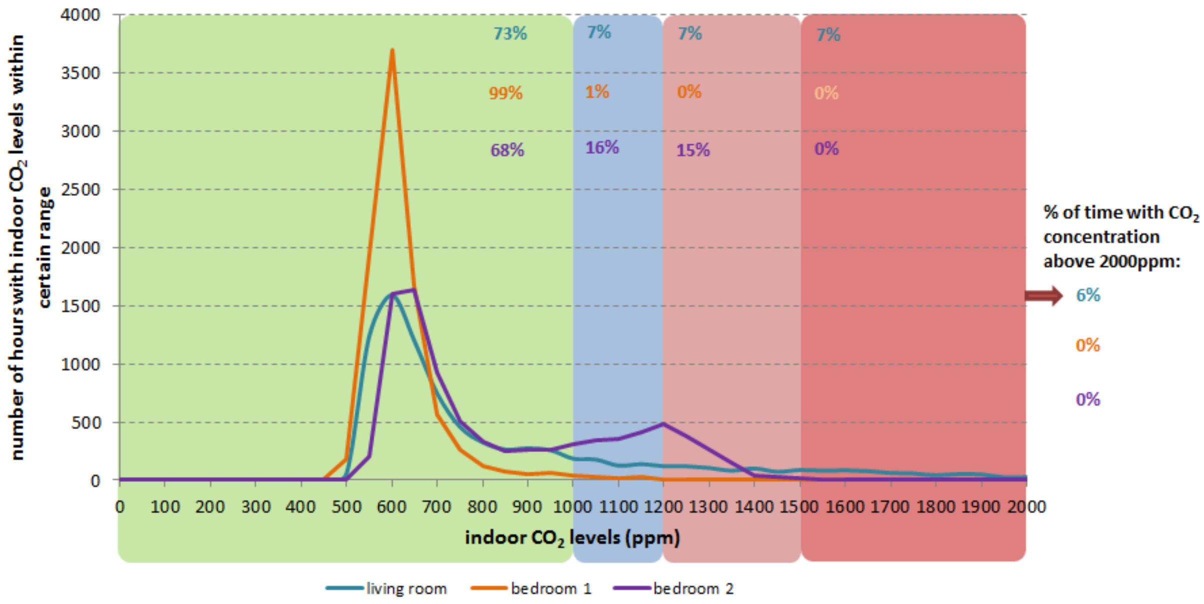


Figure 50: Roosendaal house H0400, distribution of indoor CO2 levels for 2013.

3.4.4.6.4 Roosendaal House H0600

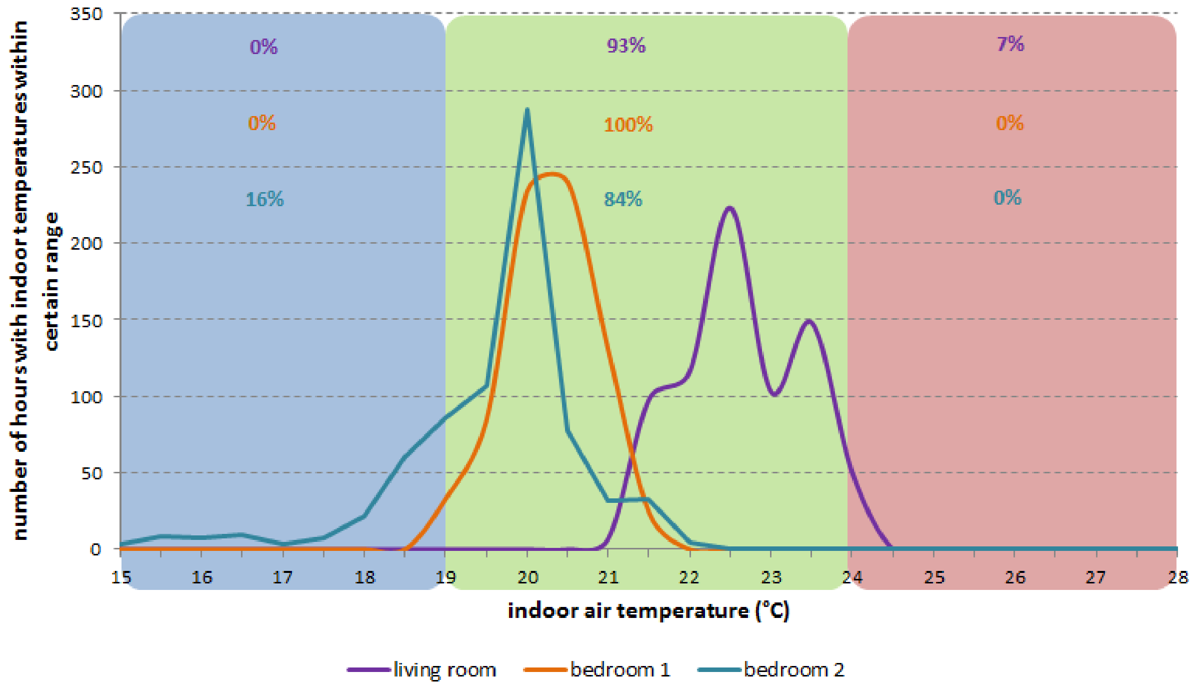


Figure 51: Roosendaal house H0600, distribution of indoor air temperatures for 2013.

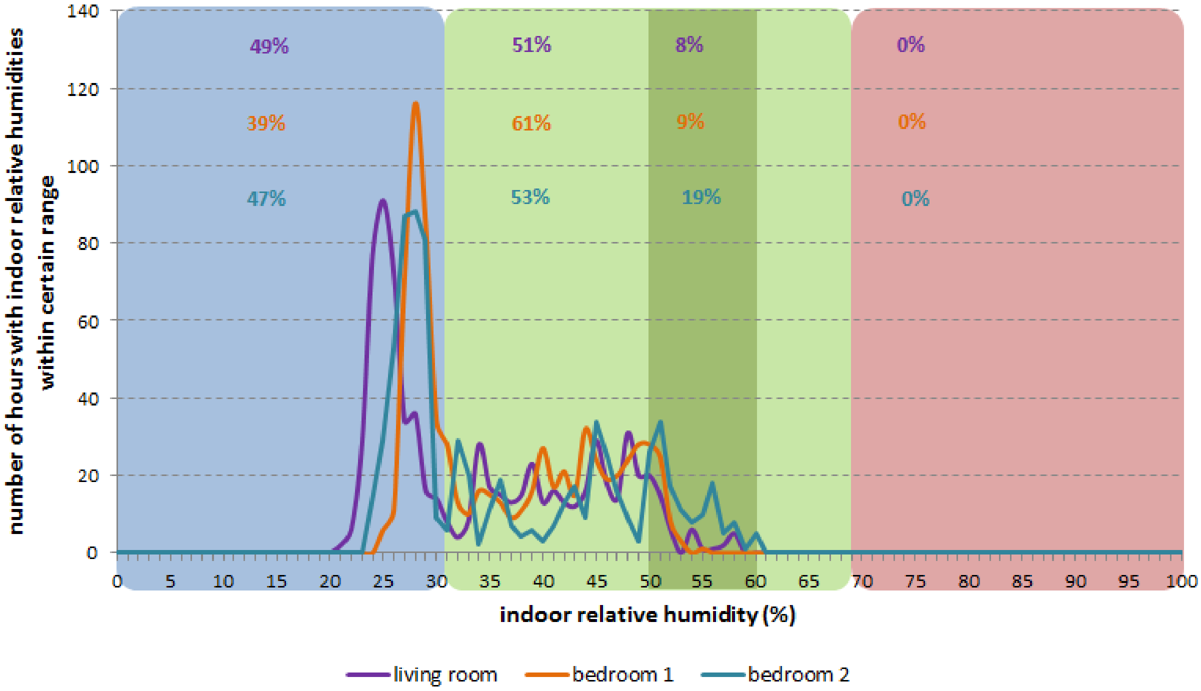


Figure 52: Roosendaal house H0600, distribution of indoor relative humidities for 2013.

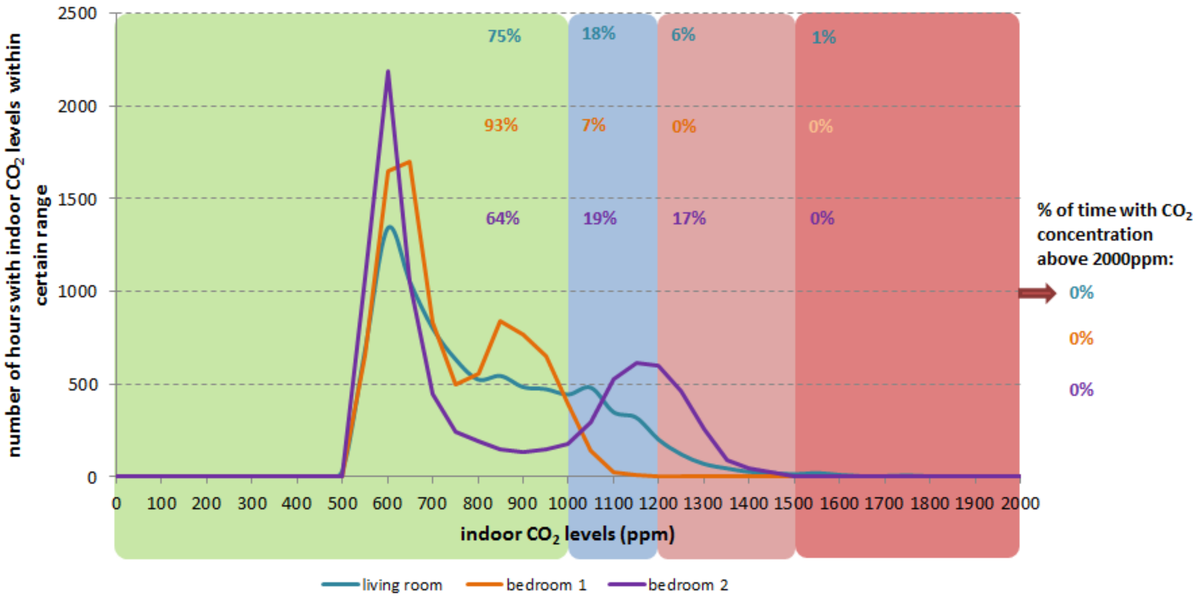


Figure 53: Roosendaal house H0600, distribution of indoor CO2 levels for 2013.

3.4.4.6.5 Roosendaal House H1000

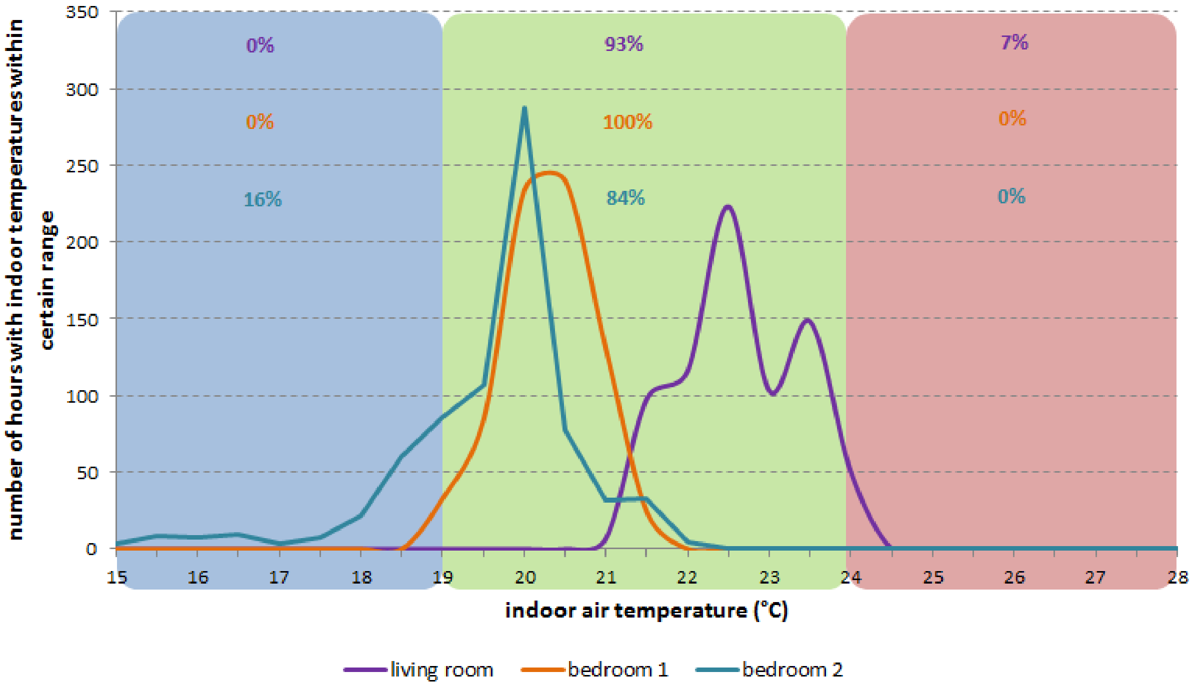


Figure 54: Roosendaal house H1000, distribution of indoor air temperatures for 2013.

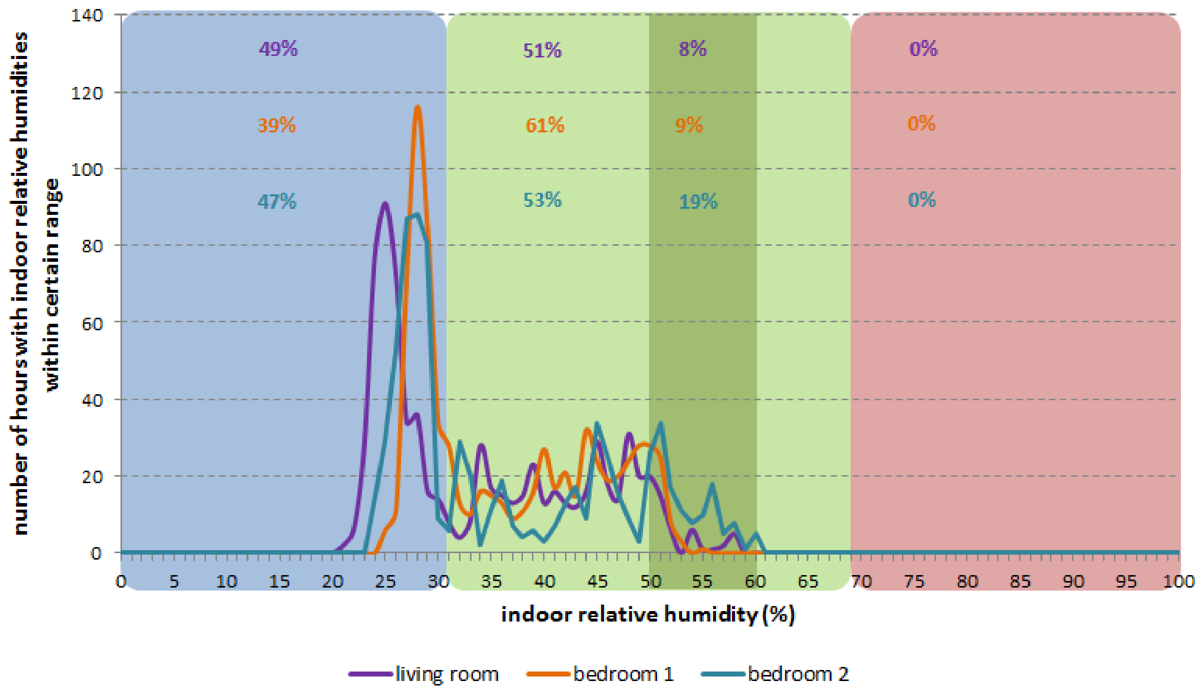


Figure 55: Roosendaal house H1000, distribution of indoor relative humidities for 2013.

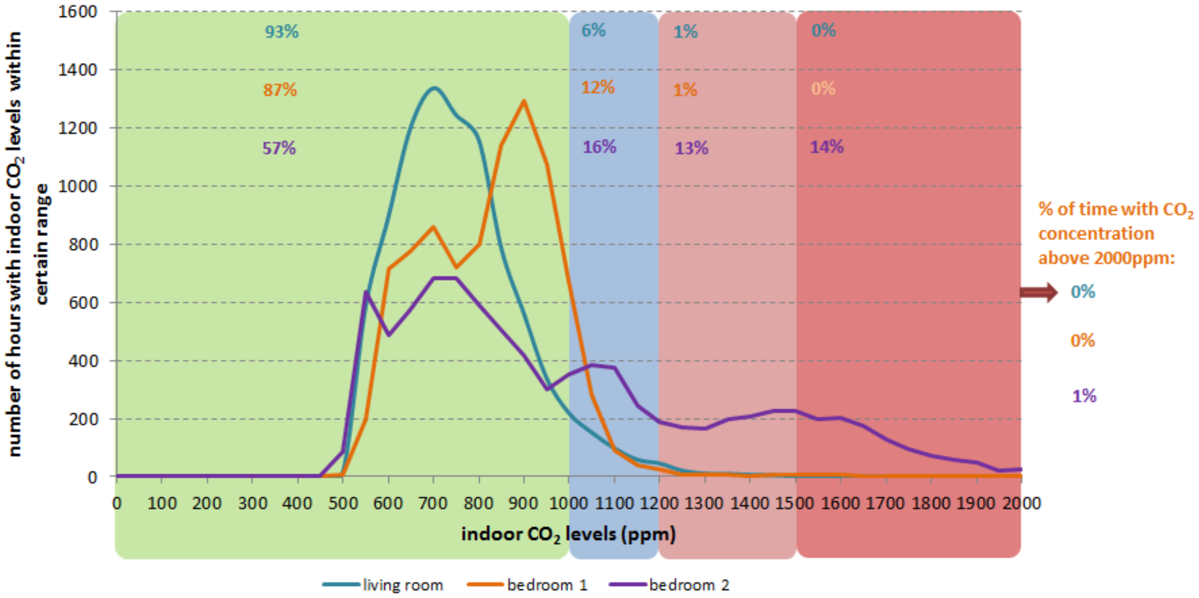


Figure 56: Roosendaal house H1000, distribution of indoor CO2 levels for 2013.

3.4.4.7 London - Evaluation of Monitored Indoor Environment

No evaluation for the London demonstration was carried out within the timeframe of E2ReBuild.

3.5 Evaluation of Tenants' Airing Habits

Within the end-user evaluation of E2ReBuild airing habits were evaluated through the tenants' questionnaire but also within the monitoring programme. Since this was a voluntary parameter of the monitoring scheme the airing habits were only included in the Roosendaal monitoring programme.

3.5.1 Tenants' Airing Habits - Frequency

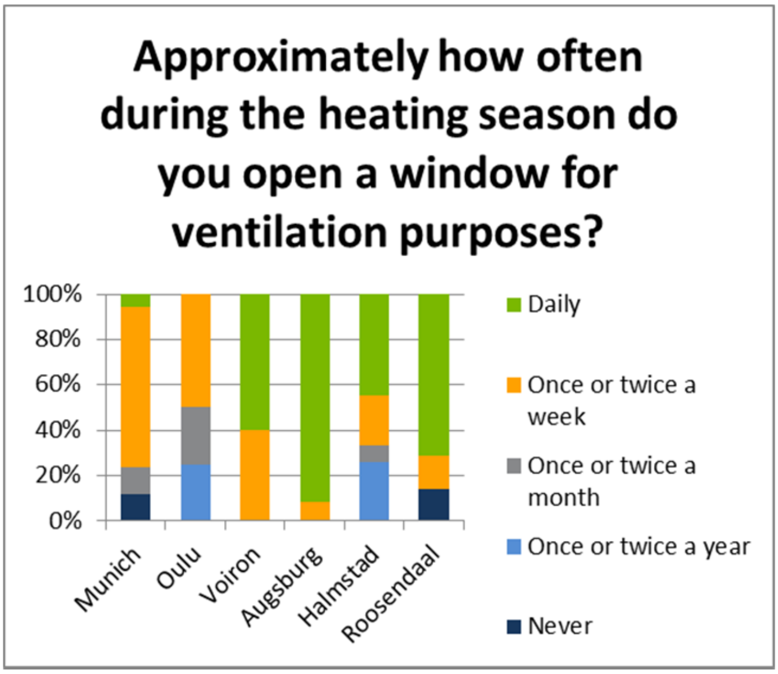


Figure 57: E2ReBuild demonstration tenants' perception on how often they open a window for ventilation purposes during the heating season.

3.5.2 Tenants' Airing Habits – Duration

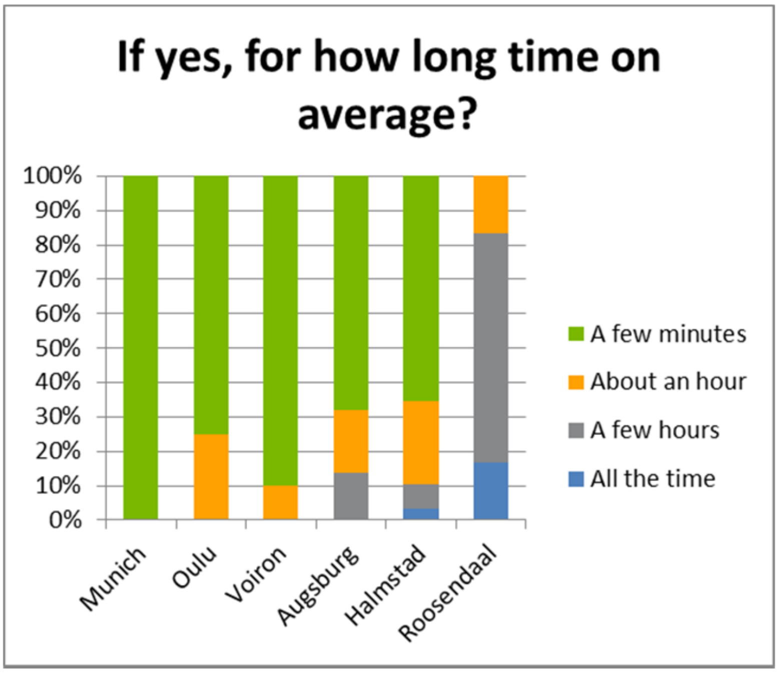


Figure 58: E2ReBuild demonstration tenants' perception on how long they open a window for ventilation purposes during the heating season.

3.5.3 Tenants' Airing Habits – Data from Monitoring at the Roosendaal Demonstration

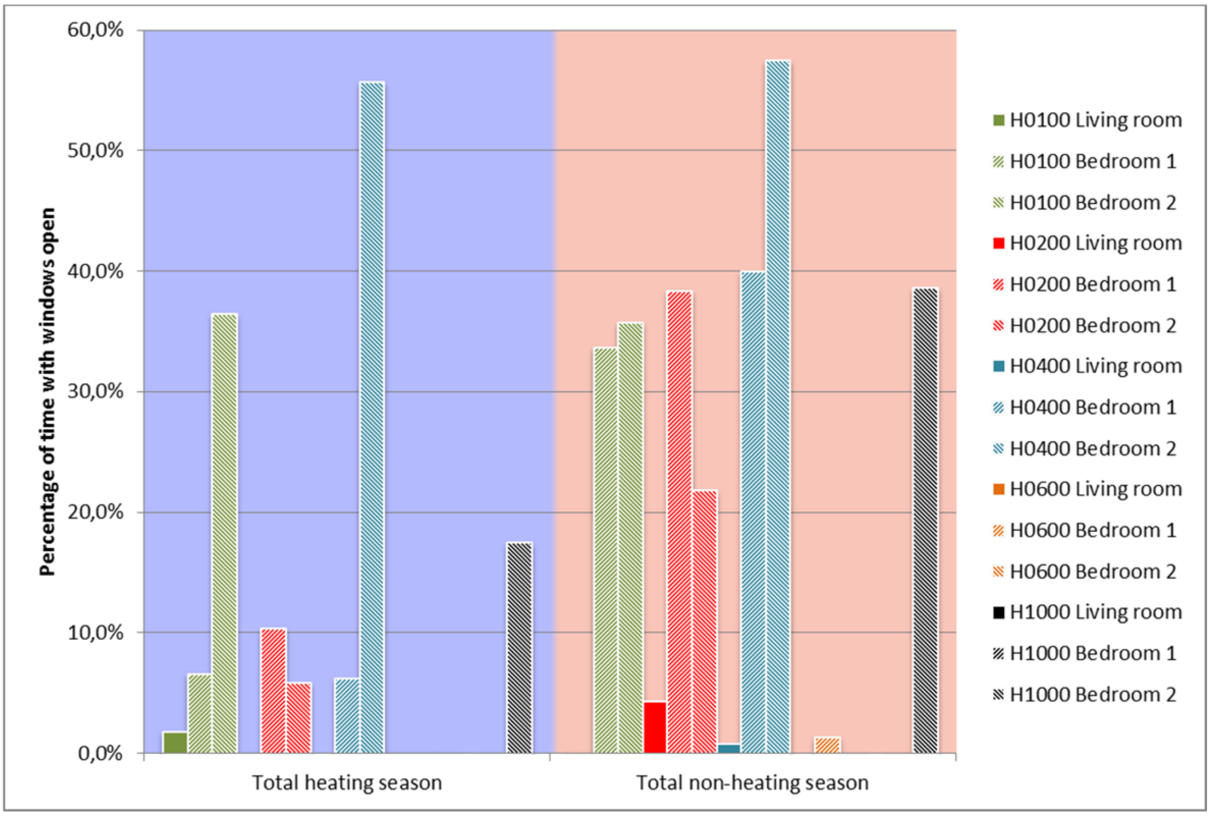


Figure 59: Airing habits at the 5 monitored houses of the Roosendaal demonstration. Percentages of time with windows open during the heating and non-heating season.

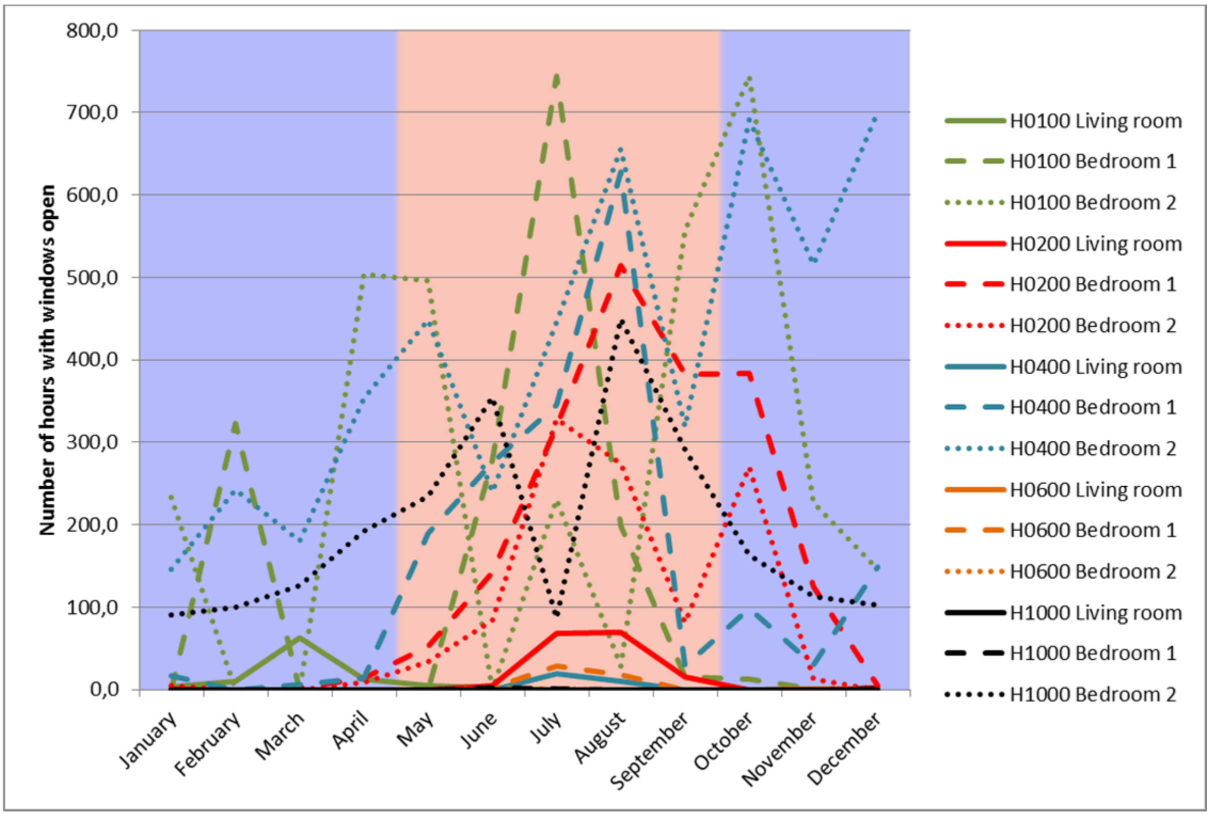


Figure 60: Airing habits at the 5 monitored houses of the Roosendaal demonstration. Numbers of hours with windows open during the year.

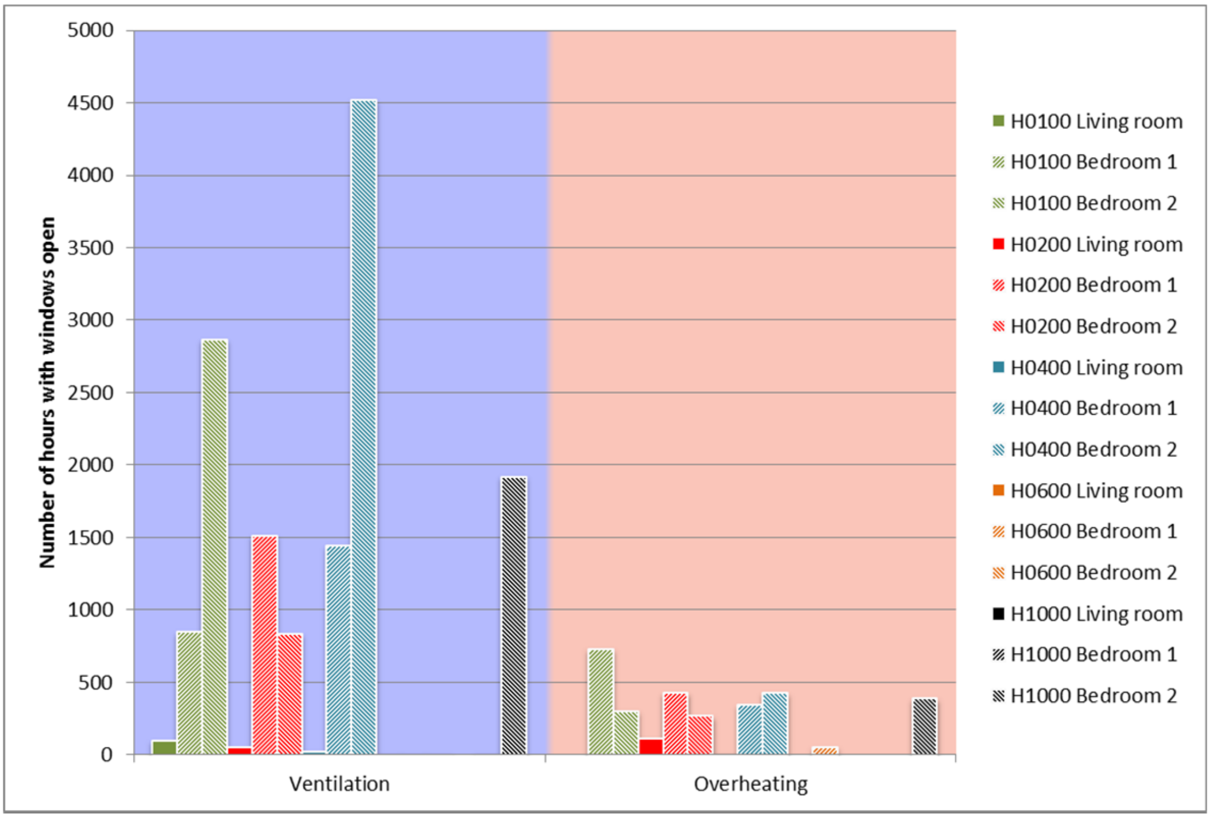


Figure 61: Airing habits at the 5 monitored houses of the Roosendaal demonstration. Indoor air temperature dependant reason for airing; ventilation for fresh air or due to overheating.

3.6 Summary and Conclusions of Experiences from the End-user Evaluation and Monitoring – Focus on Tenants' Indoor Environment

The end-user evaluation covers many different aspects that are presented in E2ReBuild deliverable D3.3 Evaluation of Case Studies and Demonstrations with the focus of Added Values. In this chapter, the tenants' indoor environment is evaluated and compared to the monitored results from the different E2ReBuild demonstrations. This highlights the tenants' perception of indoor comfort and the difficulties in evaluating indoor comfort purely based on monitored results. Sometimes monitored data can support acceptable comfort where tenants perceive problems but also the opposite can be seen.

As deliverable D3.3 presents, the indoor comfort, evaluated from the perspective of winter and summer temperature, generated several comments from tenants, and also great variances when comparing the results between the demos. Even between apartments/houses within the same demonstration great variations can be seen. Some of these variations can be explained by end-user behaviour, e.g. by different airing habits, but also as explained in the beginning of the chapter by the individual perception of thermal comfort between different persons.

In Augsburg a correlation between increased appreciation/evaluation of summer and winter temperature through the installation of winter gardens, also increasing the thermal comfort and most likely reduces the heating energy by the preheating of intake air.

Figure 62: Example of winter garden in the Augsburg demonstration. Source: Frank Lattke.

Previous research on end-user behaviour in low-energy consuming houses shows that ventilation and heating are both difficult to manage from an end-user perspective and has led to problems with air flow and indoor temperature.[7] This is an important aspect to highlight also in relation to experiences drawn from some of the E2ReBuild demos.

Following the results from the tenant questionnaire the Halmstad and Oulu demo shows decreased values within the aspect of "winter temperature". Tenants, in the questionnaires, express complaints about low winter temperatures and in Halmstad also draught from windows and ventilation. In Halmstad some tenants have adopted innovative solutions to tackle the problem of draught and cold indoor temperature by simple shutting the air inflow through applying duct tape over it. These

[7] Zalejska-Jonsson (2011) *Low-energy residential buildings, evaluation from investor and tenant perspectives*

strategies might cause a short term increase of indoor comfort but might at the same time decrease air quality and moisture in the longer perspective.

Table 13: Summary of evaluation – Munich.

Summary of evaluation – Munich		
Aspect	**Positive social impacts**	**Identified conflicts**
Tenants' indoor environment	*Overall the tenants are pleased with their indoor comfort, in particular with the indoor winter temperatures. Also, draft from windows gets a positive rating. This is probably due to the mechanical ventilation system installed in each apartment of the Munich demonstration. The supply air is then pre-heated which improves the thermal comfort. The responses from the evaluation of the airing habits show that airing is not necessary in the Munich demonstration during the heating season, and this is also supported by the monitored results indicating comfortable indoor temperatures and relative humidities.*	*Indoor summer temperatures can be too high as supported by the end-user evaluation and the monitored indoor temperatures. Overheating does occur in the summer months when outdoor temperatures are high and the shoulder months when the low sun angle can give high solar gains depending on direction of windows.*

Table 14: Summary of evaluation – Oulu.

Summary of evaluation – Oulu		
Aspect	**Positive social impacts**	**Identified conflicts**
Tenants' indoor environment	*The tenants experience their overall indoor comfort as very positive. They also give a high rating on indoor moisture which is positive since the monitored data show a high proportion of relative humidities which are very dry over the winter months. Dry indoor relative humidity during winter is expected however, since the Oulu demonstration is so far north and the outdoor absolute humidity during winter is low. Improvements can also be seen in the end-user evaluation for the indoor surface temperature of the walls which was expected given the high level of insulation added to the exterior facades.*	*Indoor winter and summer temperatures are mentioned in the end-user evaluation to be problematic for some tenants. The overheating is supported by the monitoring data but low indoor winter temperatures cannot be detected in the monitored apartment. However, the coldest months have not been included in the monitoring results and it is possible that the indoor temperature can be too low.*

Table 15: Summary of evaluation – Voiron.

Summary of evaluation – Voiron		
Aspect	**Positive social impacts**	**Identified conflicts**
Tenants' indoor environment	*The tenants of the Voiron demo are in general very happy with their indoor comfort. They rate the winter indoor comfort as very positive. This is also supported by the monitored indoor temperatures during winter which show acceptable comfort levels.*	*Summer temperatures can be disturbing for some tenants as detected by the end-user evaluation even though most tenants are pleased with their indoor comfort during summer. High indoor temperatures during summer were also detected by the monitoring data which show periods with high indoor temperatures for some apartments.*

Table 16: Summary of evaluation – Augsburg.

Summary of evaluation – Augsburg		
Aspect	**Positive social impacts**	**Identified conflicts**
Tenants' indoor environment	*The tenants are very happy with their indoor comfort on all aspects of the end-user evaluation.* *The winter garden from which fresh air is let into the apartments preheats the air and improves thermal comfort in the apartments.* *The monitored indoor temperatures during winter also show acceptable comfort levels and support the results from the end-user evaluation.*	*High CO2 levels were detected by the monitoring data. This can indicate an insufficient ventilation of the apartment but was not detected by the end-user evaluation which gave high ratings on indoor air quality.*

Table 17: Summary of evaluation - Halmstad.

Summary of evaluation – Halmstad		
Aspect	**Positive social impacts**	**Identified conflicts**
Tenants' indoor environment	*Tenants' impression of overall indoor comfort after the retrofit is high.* *The end-user evaluation shows improvement in summer indoor temperatures and indicators covering indoor air quality and indoor humidity.*	*Both indoor summer and winter temperatures were perceived as problematic by the end-user evaluation. A large variation in indoor temperatures could be detected by the monitoring data but no support could be found for low indoor winter temperatures. One reason for this could be the location of the temperature sensor in relation to the fresh air inlets. The sensation of draft from cold fresh air near the air inlets can explain the low rating of the indoor winter temperatures.*

Table 18: Summary of evaluation – Roosendaal.

Summary of evaluation – Roosendaal		
Aspect	**Positive social impacts**	**Identified conflicts**
Tenants' indoor environment	*The tenants gave a high rating for the overall indoor comfort. The end-user evaluation also shows improvements in indoor winter temperatures and interior wall surface temperatures. A positive result was also seen concerning draft from windows indicating a high improvement from a very low level. The improvement in indoor winter temperature is supported by the monitoring results showing acceptable levels of indoor winter temperatures for all monitored dwellings. The monitored indoor* CO_2 *levels support sufficient ventilation with good indoor air quality but there are variations between dwellings. Some indicate periods with higher levels of* CO_2 *and this is also reflected in the airing habits of the Roosendaal tenants. In Roosendaal the tenants open their windows more frequently than most other demonstrations and keep them open for longer periods.*	*Indoor summer temperatures can be problematic as indicated by the end-user evaluation and supported by the monitoring on indoor temperatures and airing habits. Also, the indoor relative humidity gets a low rating. As explained in the beginning of the chapter, this is often the case for dwellings with balanced ventilation, and the findings are supported by the monitoring data.*

4 Guidelines for an Automatic Control System and Routines for Continuous Following-up of Indoor Environment and Energy Use

4.1 Introduction

The technology is available today which allows building owners to follow and even control almost every aspect of their building's performance, in real time. The demonstrations in E2ReBuild showed a couple of different methods of following up and controlling the indoor environment and energy use with remote systems. One method, used by Giganten 1&7 in Halmstad, had an advanced monitoring and control system, similar to that used in process intensive industries such as paper mills, which allowed the building owner to control and monitor all of Giganten 1&7's systems in real time. The big question that the building owner must decide, is how much of this information and control be given to the building's occupants?

In Giganten 1&7 indoor environment was monitored using indoor air temperature sensors in two or more apartments per floor. Each sensor was connected to a logging server in the basement of the building and the data was accessible via Internet to ABV. No visible value could be seen by the tenant on the sensor. This was intentional so that the tenants would not be interested in the sensor.

These sensors could have been easily upgraded to more advanced measuring equipment capable of measuring temperature, Relative Humidity and CO_2 levels in each apartment.

In the Finnish demonstration in Oulu however, displays were installed for tenants' visualization which included electricity, domestic hot water and cold water usage.

4.2 Automatic Control System

One strategy of reducing energy use in a building is by utilizing an automatic control system. This technology can apply incremental power to a system instead of on/off at the right time. This means that the system provides enough power for the system and not too much at any given time. In a more advanced system this means only activating enough systems to match the energy demand and not all of the systems.

Another advantage of an automatic control system is that the system is able to monitor itself and report problems to the facility's manager. If the issue is minor, the system can readjust itself and solve issue without triggering an error message or requiring a person to adjust the system.

Automatic control systems may also be programmed to make use of night billing. In some locations, energy is cheaper at night in order to promote a more even balance of energy use in the grid. Automatic systems could also be configured to take advantage of this, lowering the energy costs.

In the most advanced systems, a prognosis control system can work with an automatic system and make it proactive. The system uses weather forecasts to control the heating/cooling systems. This decreases the total energy use by making use of a building's thermal capacity. If the forecast says that the weather will be cold the following day, the heating system can begin warming the building the day before, storing heat in the structure of the building. When the outdoor climate gets cold, the heating system does not have to be at maximum power since stored heat is given off by the building's structure. In the same way, if it is cold and prognosis gives warm weather, the heating system can provide less heat before the warm period. In practice, the system cuts off the peak power when it gets cold or warm. The estimated energy savings is between 5 and 10 %.

4.3 Routines for Continuous Follow up of Indoor Environment and Energy Use

This routine can be used as a guide when thinking about how to design and implement a monitoring system in a building. This can be followed either when doing the work internally or in cooperation with a company specializing in data monitoring and collection, although it is recommended that a company which specializes in measurement systems be used. Advanced monitoring and control systems are much more difficult to optimize and troubleshoot when problems occur. This routine can be used by the building owner as a guide to better understand or define what their monitoring system is capable of when implemented:

1. Define all the parameters which are interesting. Some examples are temperature, Relative Humidity, CO_2 concentration, cold water temperature, hot water temperature, energy flow to heat pump 1, energy flow to parking garage, water flows, outdoor temperature, etc. (can be hundreds of data points depending on the level of information that is desired!)
2. Use schematic drawings to decide the optimal measurement point for each sensor/meter
3. Define the minimum level of accuracy for the different measurements (higher level of accuracy usually means higher costs, what level is good enough?).
4. Define how often data should be logged (every second, minute, hour or day)
5. Define what kind of measurement (direct reading, integrated over time)
6. Decide who gets access to what data. For example, will the tenants be accessing any data or is it just for the building's facility manager?
7. Decide how this data should be accessed (locally, via Internet or via remote storage on an external server).
8. Based on steps 1 to 6 design the data storage system so that the storage system has enough capacity to store data for a defined period of time, for example five years.
9. Produce a specification of all the needed sensors, meters and other logging equipment.
10. Install all the measuring equipment.
11. Ensure that the system functions as designed.
12. Make energy use an annual topic where the data is analysed, summarized, presented in order to judge the operation of the building's systems.
13. Adjust or repair the affected systems if the results from the energy follow up indicate problems.

4.4 E2ReBuild Demonstrations Experiences on Routines for Continuous Following-up of Indoor Environment and Energy Use

At the 7 E2ReBuild demonstrations routines for continuous following-up of indoor environment and energy use has been implemented to different extent. In Table 19 below the experiences are summarised and evaluated.

Table 19: Experiences from the demonstrations on routines for continuous following-up of indoor environment and energy use

Lessons learned – experiences from demonstrations	
Munich	Building energy demand and generation will be monitored. On dwelling level annual energy consumption, including DHW, household electricity is metered; no further monitoring will be done concerning the IAQ or building performance.
Oulu	No routines have been established beyond E2ReBuild research period. It will be necessary to include this building into subsequent research projects to keep the monitoring evaluation ongoing. The building owner does routine checks on water, electricity and district heating consumption, and standard equipment maintenance.
Voiron	An excel « database » has been implemented with monthly data from energy meter and temperature to follow-up energy use.
Augsburg	Nothing.
Halmstad	NCC has a guaranteed the energy use in this building. Both NCC and Apartment Bostad (now Akelius) will be monitoring both the energy use and indoor temperatures in the future. Any problems will be dealt with by Apartment Bostad.
Roosendaal	No.
London	This is not currently part of our (Cogent's) work in providing a monitoring solution

5 Evaluation of the TES Energy Façade System at Two of the E2ReBuild Demonstrations

In this chapter a shortened version of the paper *Hygrothermal Performance of TES Energy Façade at two European residential building demonstrations – Comparison between Field Measurements and Simulations* is presented. The full paper has been accepted to the NSB2014 conference in Lund, Sweden.

As part of the E2ReBuild monitoring scheme, deliverable D5.1, hygrothermal monitoring was established in the building envelopes for two of the demonstrations. In this chapter the findings from the monitored facades are compared with hygrothermal computer simulations and evaluated.

5.1 Introduction

In this study, the retrofitted facades of two E2ReBuild buildings are investigated. The demonstration buildings are Munich, Germany and Oulu, Finland. The demonstration in Munich consisted of two blocks of residential multi-storey buildings, built in 1954. The buildings were typical examples of the concrete brick constructions, built throughout Germany in the post-war era. The demonstration in Oulu, northern Finland, is a student apartment building. This building was completed in 1985 using prefabricated concrete elements for residential buildings, called the "BES system" (Cronhjort 2014). To improve both demonstrations energy performance, the retrofit included a façade refurbishment with the TES method utilizing timber based, prefabricated façade elements for the renewal of the building envelope. As part of the E2ReBuild monitoring programme presented in deliverable D5.1, hygrothermal gauges were installed in the walls and they have been monitored for more than one year after the retrofitting. In this chapter some of the results from the in-situ measurements of the two demonstrations are presented and the findings are compared to calculated transient hygrothermal 2D-simulations (*Künzel 1995, Holm 2000*) of the facades utilising the monitored data from the sites in Finland and Germany.

External thermal insulation systems are commonly used to improve the thermal performance of such buildings, and for the two selected buildings of the E2ReBuild project the TES-method was chosen for improving the building envelope performance. The TES-system and method utilises timber based and insulated prefabricated façade elements for the renewal of the building envelope and to improve its thermal performance (*Lattke 2011, Cronhjort 2014*). In this study, the hygrothermal effects caused by the refurbishment are investigated and the TES-system is evaluated from a moisture safety point-of-view.

5.2 Description of Demonstration Buildings and Field Measurements

5.2.1 Background on Munich Demo

The Munich demonstration built in 1954 consists of two blocks of residential buildings. They are examples of typical concrete block constructions built throughout Germany after World War 2. The refurbishment concept includes a significant dismantling of the existing dwellings, built from light weight concrete block walls and concrete ceilings. The building was stripped down to the primary structure and the roof was taken off, see Figure 63. Additional changes in floor plan layout and new circulation cause interventions on the interior walls as well as on the window openings. A new attic floor and a roof were added together with an entire new building envelope made from TES Energy Façade elements.

Figure 63: Dismantled structure of Munich demonstration with new elevator shaft (Photo: Lichtblau Architects).

The highly insulated exterior wall with triple glazed windows is the backbone of the building envelope, see Table 20. The heating system is supplied from the district heating grid. On sunny days it is supported by solar thermal panels on the roof with a large accumulator tank containing 20000 litres of water as buffer. Room heating is done by radiators. The apartments have decentralised ventilation units with plate heat exchangers. The highly insulated building envelope, together with a modern and efficient ventilation system with heat recovery, means that the tenants enjoy an energy-efficient apartment with a high level of thermal comfort.

Table 20 Facts about thermal performance of envelope and building services, Munich demonstration.

	before	after
Exterior walls and roof	1.8 W/m²K	0.15 W/m²K
Windows	2.5 W/m²K	0.9 W/m²K
Basement ceiling	1.55 W/m²a	0.45 W/m²K
Heating energy (calculated)	280 kWh/m²a	21.2 kWh/m²a
Primary energy (calculated)	343 kWh/m²a	23.5 kWh/m²a

5.2.2 Background on Oulu Demo

The Finnish demonstration building underwent a complete retrofitting of the envelope, see Table 21. The old façade layers of the previous BES-systems were removed leaving only the inner concrete layer in place. The new façade was retrofitted using TES Energy Façade elements, see Figure 64. The old roof was completely replaced by a new timber truss roof and a new thermal insulation layer. The existing ground floor slab was replaced, with a new in-situ concrete ground floor slab with EPS insulation.

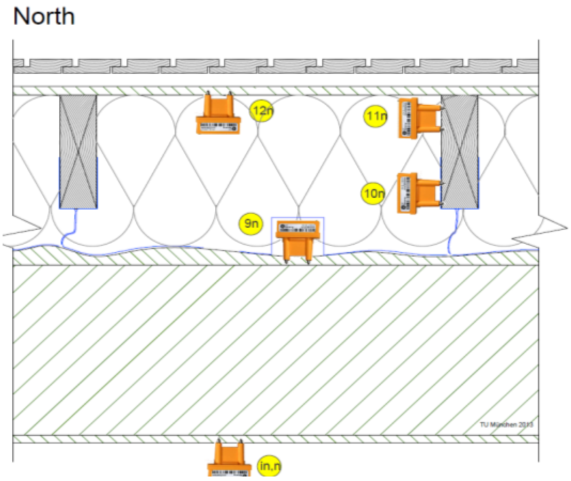
Table 21 Facts about thermal performance of building envelope, Oulu demonstration.

	before	After
Exterior walls and roof	0.28 W/m²K	0.11 W/m²K
Windows	2.1 W/m²K	0.8 W/m²K
Ground slab	0.24/0.36 W/m²a	0.11/0.15 W/m²K
Roof	0.22 W/m²a	0.08 W/m²a

Figure 64: Oulu demonstration during assembly of prefabricated TES elements (Photo: Simon Le Roux).

5.3 On-site Hygrothermal Monitoring of the Facades

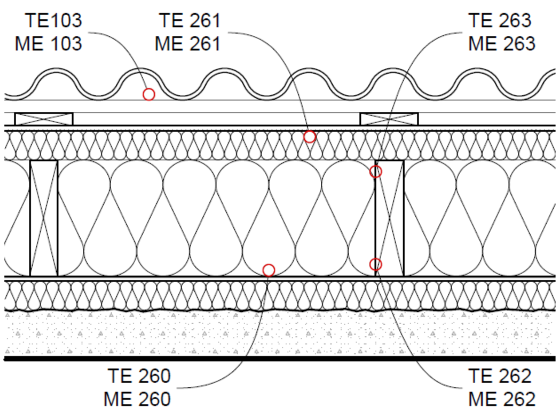
Part of this study includes an analysis of the TES Energy Façade elements with regards to hygrothermal performance, i.e. thermal and moisture performance of the exterior wall. Figure 65 shows where each of the wireless hygrothermal sensors was placed in the north façade of the Munich demonstration.



- wood shuttering formwork 24 mm
- air layer / lathing horizontal 24 mm
- gypsum fibre board 15 mm
- construction wood / cellulose 200 mm
- adaption layer – cellulose 60 mm
- membrane, Sd-value = 5 m
- exist. plaster, lime-cement plaster 25 mm
- existing exterior wall, light-weight concrete building blocks 300 mm
- exist. plaster, lime-cement plaster 15 mm

Figure 65: Monitoring positions of the Munich TES Façade element.

For the Oulu demonstration in Finland there was a similar set up of monitoring positions of the facades, as shown in Figure 66. Also facing north, the retrofitted wall construction consisted of:



Declared U-value of the finished wall is 0.11 W/m^{2}K

- 7mm corrugated fibre cement cladding
- 44 mm air gap
- 22 + 22x100mm timber battens
- 9mm gypsum wind barrier
- 50 + 200mm glass mineral wool slab (Lambda 0,033 W/mK)
- 42x48mm c600mm horizontal timber battens
- 42x198mm c600mm timber load bearing frame
- 9 mm plywood board
- 50 mm soft thermal insulation
- 80mm existing precast concrete

Figure 66: Monitoring positions of the presented Oulu TES Façade element.

5.3.1 Measured Data

For the Munich demo temperature, relative humidity and moisture content were measured at the measurement points shown in Figure 65 between 2012 and 2013. This data was measured every hour and was uploaded to a server where it could be monitored and downloaded. The sensors are wireless and had difficulties in sending their data every hour during the measurement period so a number of data points are missing.

For the Oulu demo, temperature and relative humidity was monitored at the measurement points shown in Figure 66 from February 2013 and is still on-going (June 2014). Here however, a wired system was used for the sensors and more continuous results are available.

5.4 Hygrothermal Modelling and Simulation

The hygrothermal behaviour of the demonstration buildings facades has been modelled by the two-dimensional hygrothermal building envelope tool WUFI 2D 3.3. The software has been experimentally verified for many types of building component assemblies (Künzel 1995, Karagiozis 2001) and similar set-ups (Holm 2000, Tariku 2006).

Material data and initial moisture conditions were supplied from material databases such as MASEA Datenbank (Materialdatensammlung für die energetische Altbausanierung) and the IBP Fraunhofer Material Database. As the buildings are between 30 to 60 years old, the German demonstration originates from the early 1950-ies, there is some lack of precise historic material data and appropriate assumptions had to be made for existing materials in the old wall structures.

5.4.1 Munich Demonstration

Together with measured climate data during the period of January 1, 2012 to October 28, 2013, WUFI 2D simulations were performed using the drawing shown in Figure 65. Material properties were mostly taken from the Default materials database in WUFI.

For the existing wall the specific material is unknown with unknown thermal and moisture properties. However, it is known that the material is a type of Leca block with aerated aggregate. The real lambda value of the old wall was calculated using the measured indoor temperatures, temperatures in the adaption layer and temperatures in the exterior part of the mineral wool. These calculations showed that the lambda value of the old wall in reality is between 0.09 and 0.12 W/mK, which is similar to the thermal properties of the default materials Light Expanded Clay Aggregate and Aerated concrete. At the beginning of the calculation, the initial moisture levels of all materials were set to about 80 % relative humidity, based on measured values from the demonstration.

5.4.2 Oulu Demonstration

For the Finnish demonstration the WUFI 2D simulations were set-up according to the drawing shown in Figure 66 together with measured climate data for the period of March 2013 to March 2014. An initial relative humidity throughout the existing construction of 60 % was assumed since this was an old construction and should not contain any excess moisture. In the air gap behind the cladding a modest ventilation rate of 5 air changes per hour (5 ACH) was used for the simulation.

5.5 Results

For both E2ReBuild demonstrations the measured results agree quite well with simulated results. The temperatures correlate very well as does the moisture levels; however, the measured data shows much more variation in moisture levels than the simulated data.

5.5.1 Munich

The simulated results are taken from the mineral wool where the sensors were located. It is interesting to see that even though they are the same points, the calculations show a much more stable moisture level in the wall than in reality.

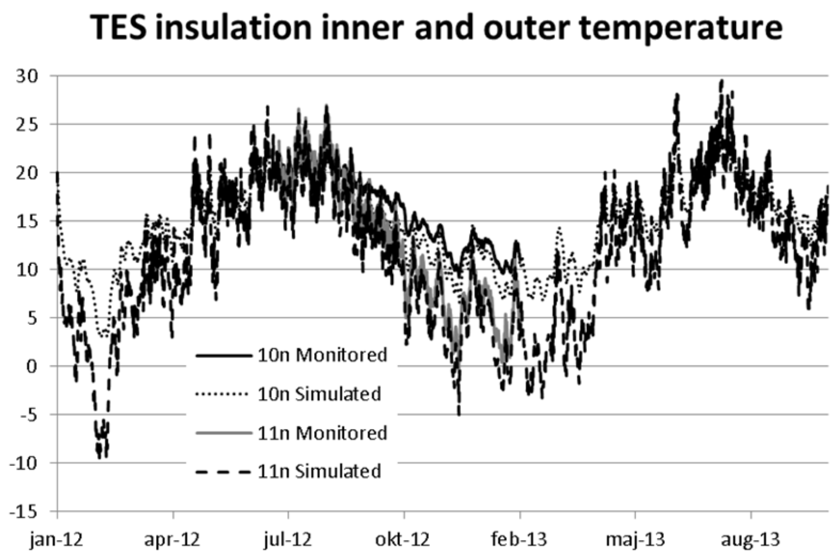


Figure 67: Temperature and relative humidity for the Munich TES Façade elements insulation, inner (10n) location.

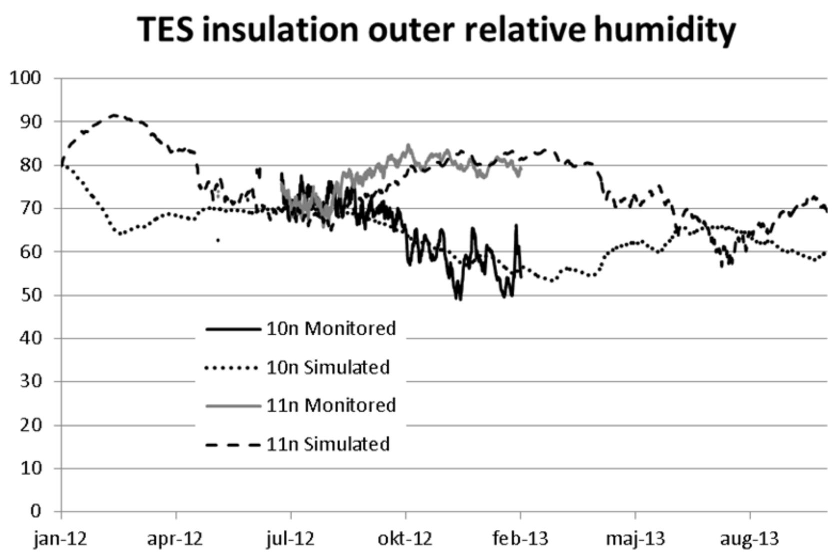


Figure 68: Temperature and relative humidity for the Munich TES Façade elements insulation, outer (11n) location.

The moisture levels in the exterior of the wall correlate well; however, the calculated moisture level in the middle of the wall (point 9n in Figure 65) does not match the measured values. Further calculations seem to indicate that the plastic vapour barrier may be punctured at the sensor; the results show that measurement point 9n is affected by the exterior climate more than it should be if the vapour barrier was complete.

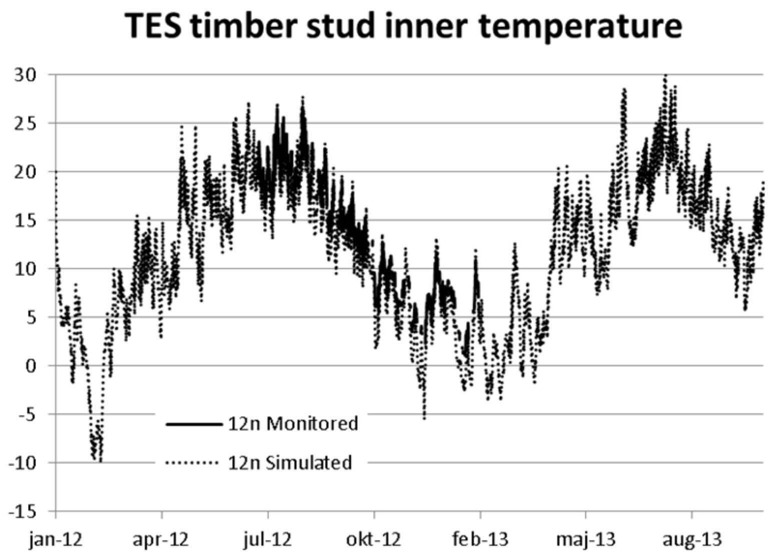


Figure 69: Monitored and simulated temperature for the Munich TES Façade elements timber stud (12n).

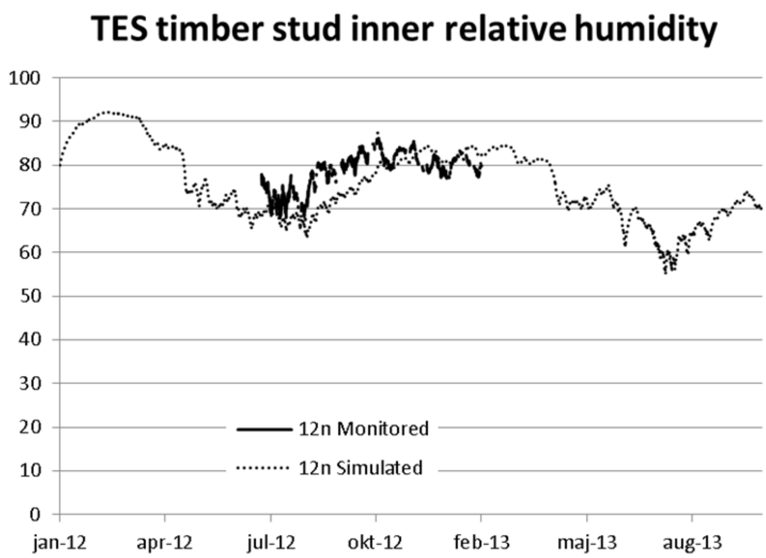


Figure 70: Monitored and simulated relative humidity for the Munich TES Façade elements timber stud (12n).

For both the calculated and measured results, there does not appear to be a significant moisture risk associated with TES Energy Façade in Munich over the long term. The trend that can be seen in the WUFI calculation is that the construction dries out over time. However, a longer time period is necessary to ascertain this trend and to verify the simulations.

5.5.2 Oulu

The simulated values correlate well with the measured results, in particular regarding temperatures in the wall. The results show that the initial moisture level has a significant influence on the simulated values; the relative humidity is too low for the outer part of the wooden studs but for the inner part the simulation is well in accordance with the monitored result. After some months the levels are very close to the measured values and the monitored wall is getting dryer. The low, 5 ACH, ventilation rate give accurate readings during many periods, but often seem to be underestimated as larger fluctuations can be seen in the relative humidity on the inside of the outdoor gypsum board. Another possible reason for the fluctuations can indicate insufficient air tightness over the wind barrier, causing larger fluctuations in the monitored results of the insulation compared to the simulated results.

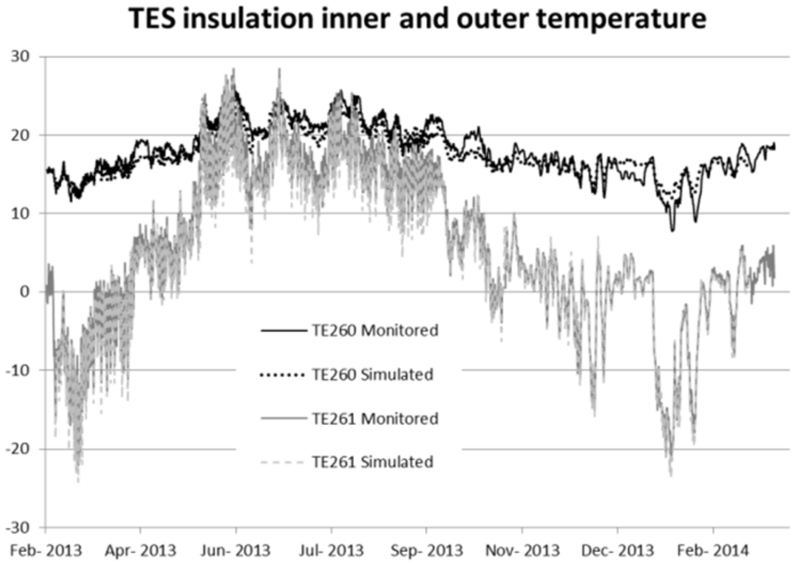


Figure 71: Monitored and simulated temperature for the Oulu TES Façade elements insulation, inner (TE/ME260) and outer (TE/ME261) locations.

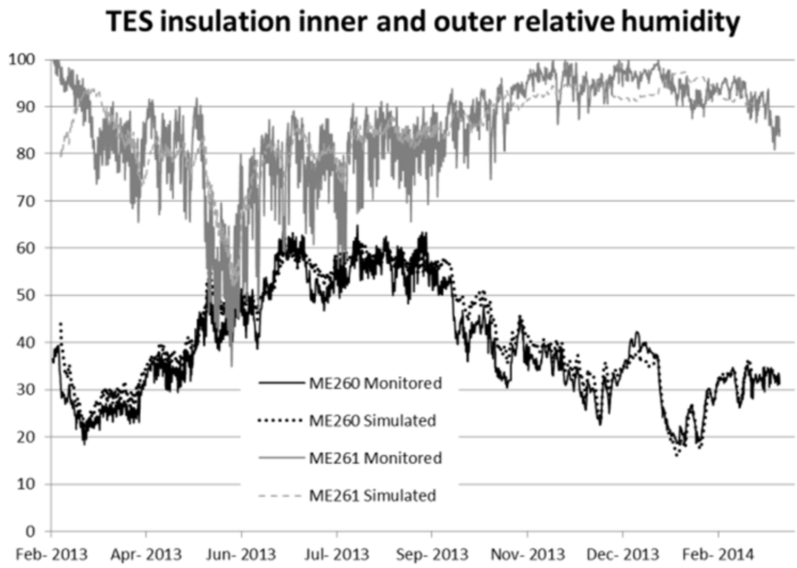


Figure 72: Monitored and simulated relative humidity for the Oulu TES Façade elements insulation, inner (TE/ME260) and outer (TE/ME261) locations.

The extra insulation placed outside the wooden studs has a clear beneficial influence on the temperature and relative humidity of the studs. Comparing the relative humidity for the monitoring position of the TES outer insulation (ME261) to the relative humidity at the TES outer part of the timber studs (ME263), clearly shows the reduction in relative humidity. Not only does the insulation break the thermal bridge, it also raises the temperature of the studs outer parts compared to a case without extra insulation, and this gives lower relative humidity and risk of moisture damage. This is an important finding concerning moisture safety and long-term durability.

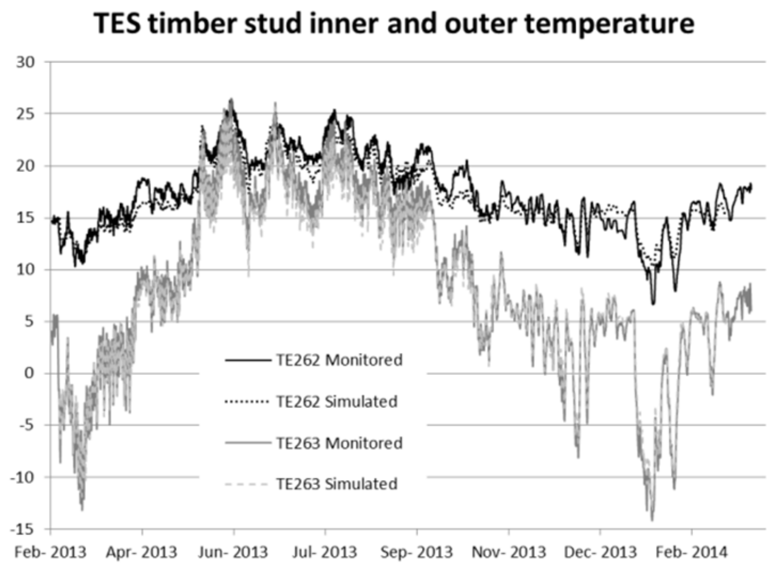


Figure 73: Monitored and simulated temperature for the Oulu TES Façade elements timber studs, inner (TE/ME262) and outer (TE/ME263) locations.

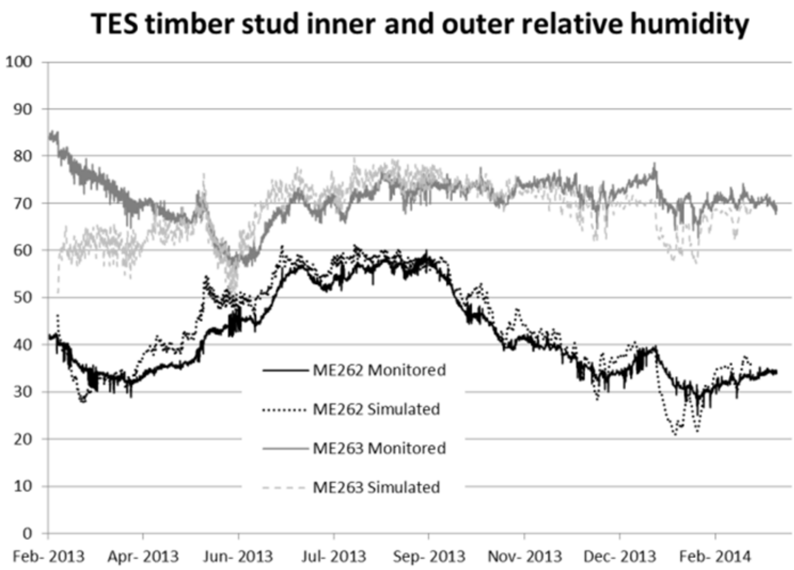


Figure 74: Monitored and simulated relative humidity for the Oulu TES Façade elements timber studs, inner (TE/ME262) and outer (TE/ME263) locations.

5.6 Conclusions

In conclusion, the two cases from Munich and Oulu show that WUFI 2D is a good tool to determine the moisture performance of the TES Energy Façade after a renovation. However, the results are very sensitive to the input data such as the existing wall, climate data, the new building materials and if there is any problem with the quality of the work on site. The demo cases also show that the risks for moisture damage in the form of mould growth in the TES Energy Façade are quite low in both cases for the measured climate. This gives an excellent possibility to evaluate TES Energy Façade with different modifications and in new locations using hygrothermal simulations before actually starting the retrofit of a building. Initial moisture can pose a risk for wooden construction, both elevated moisture contents in the TES wooden studs themselves, but also in the interior and existing wall material where the TES will be placed can be a source of excess moisture, especially for materials such as concrete and lightweight concrete. It is always important to keep materials dry and not exposing them to rain or ground moisture during transport, storage or construction.

For future work it would be interesting to see the effect of built-in moisture in the existing wall on the hygrothermal performance of the external TES timber studs and the risk of moisture damage this would impose. Also, the robustness and sensitivity of the system to moisture from envelope leakage or from transport to construction site is a topic that needs further investigation, as well as the effect of the extra layer of insulation on the timber studs in the Finnish demo compared to the German TES build-up without the extra layer of insulation.

Both demonstrations have collected data on many other locations of the building envelopes and this can be used for future research outside of the E2ReBuild project.

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