MUSEUM AMSTELKRING IN AMSTERDAM

Advisory report, indoor climate control

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-CONCEPT-
03-23-2006

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BPS-report 05.20.K
Sub department BPS
March 2006

Translated from Dutch into English by IDEM Translations, Inc., 2008

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Introduction

The Amstelkring Museum is located on Oudezijds Voorburgwal in Amsterdam. The building is a 350-year old canal house and has been open to visitors for more than 120 years. All areas such as living rooms, kitchens, corridors and staircases are still essentially in their original condition. On the upper floors of the house, there is a clandestine church “*Ons’ Lieve Heer op Solder*" [Our Lord in the Attic], which is still in use, for example, for wedding ceremonies. Works of art belonging to the museum and on loan are on display. In 2004, nearly 75,000 people visited the museum.

A preliminary investigation by the TUE [1] showed that the museum has to deal with a number of problems related to the indoor climate:

- Condensation on the windows and the outside walls
- Unsuitable relative humidity of the air for preservation of the collection: conditions are often too moist or too dry
- Stuffy in the summer: very warm with high concentrations of CO_2 in certain rooms resulting from very low air exchange rates
- Dry rot and wood borers: possibly caused by excessively humid air and surface condensation

The windows are opened to provide some cooling and ventilation in the summer, which lets in unfiltered outside air. This can cause other problems such as fluctuations of the indoor climate, indoor air pollution and insects.

In the framework of this investigation solutions to these problems will be sought, such as for example, the installation of a suitable ventilation system. The investigation consists of a global building physical analysis, an inventory of the existing climate control installation, long-term measurement of indoor conditions and a study of possible solutions via simulation studies.

1. Building Physical Inventory

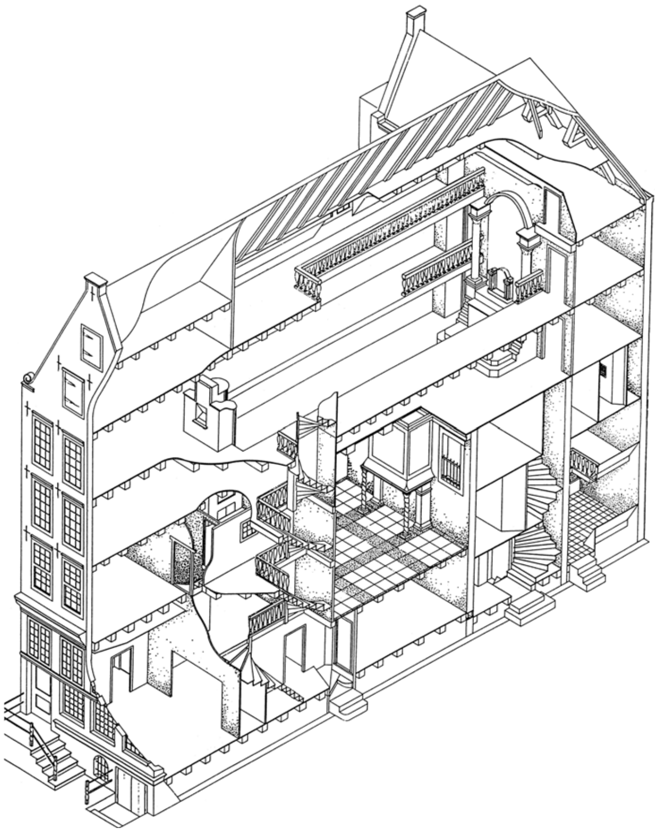


Figure 1 A cross-section of the building showing the floor, wall and roof structure.

Building orientation

The main entrance of the building on Oudezijds Voorburgwal faces south-east. See Figure 2 for a graphic presentation of the building orientation.

Walls

Outside walls and internal load-bearing walls are made of bricks (Dutch cross) ± 0.3 m deep. There is additional masonry on the outside, and it is stuccoed on the inside and covered with a white finishing layer. On the lower floors, the walls are partially tiled.

Floors

The floors and galleries consist of wooden beams and planks. The church ceiling is stuccoed. Some floors, such as the one in the Sael are tiled. The Sael has a coffered (or cassette) ceiling.

Roof

The roof is constructed with wooden beams, sheathing and roof tiles. It is not insulated.

Glass

The museum windows are single-pane glass. A Plexiglas pane has been installed on the inside of the windows on the north-east and south-east walls. This is to protect against UV, and also to prevent damage to the museum should, for example, a rock be thrown through the window.

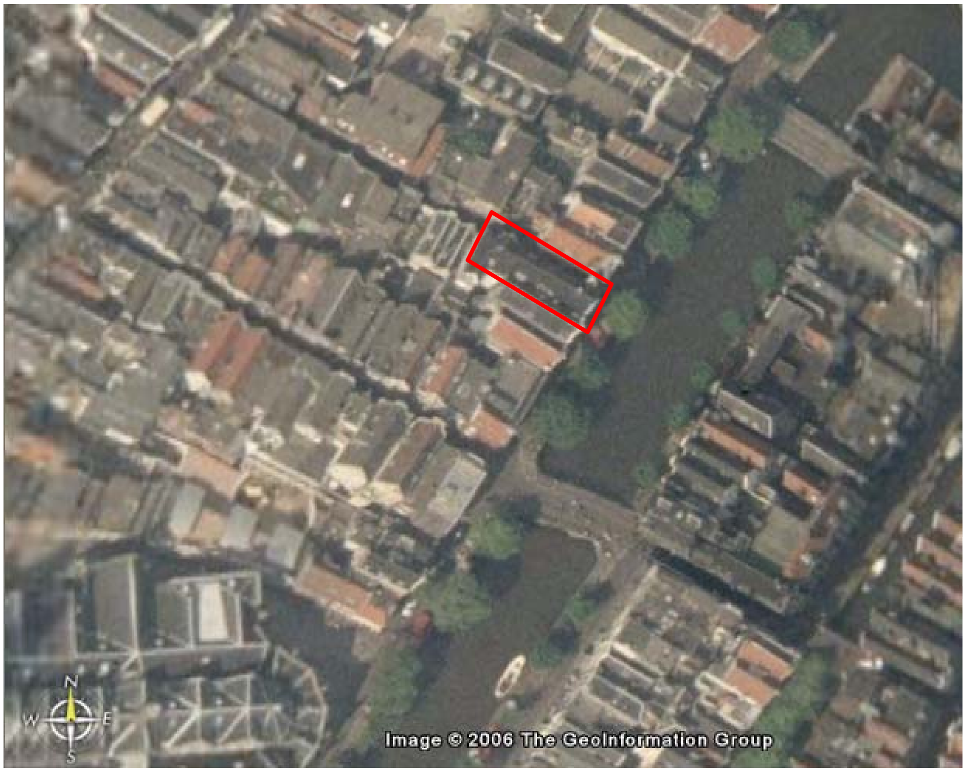


Figure 2 Satellite photo of the building. The facade of the building on the canal-side faces south-east.

2. Heating system

Heating of Individual Rooms

The museum is heated by two gas stoves and a central heating system. Unfortunately, no diagrams of the heating system are available. There are, however, overall structural drawings of the building available on which the heating elements were drawn in after a visual inspection had been made (see figures 3 through 6).

Gas stoves

There are 2 gas stoves installed in the museum, i.e., in the antechamber on the ground floor, and on the 1st floor in the Canal room. The oxygen the stoves require for combustion is removed from the ambient air. The flu gases are removed by ductwork through a structural shaft, and vented above the roof.

Figure 3 The gas stoves installed in the antechamber (left) and the Canal room (right).

Gas stove in the antechamber: Pelgrim Bambino type
Output 9.4 kW
Manual controls
Open device

Gas stove in Canal room: Plate steel with a type 28 Pelgrim interior
Capacity: 5.6 kW
Manual controls
Open device

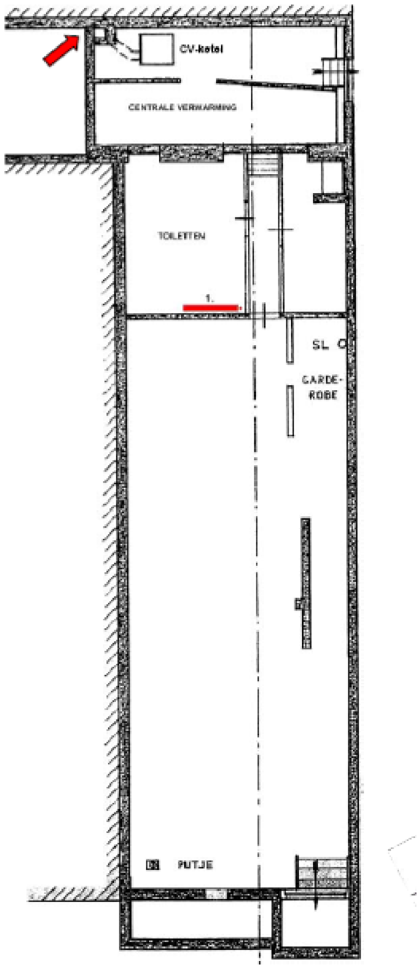
Heating elements

The rooms are heated using radiators and convectors, which are connected to a 2-pipe system. There are various manufacturers and types:

- Plate radiators mfg. Veha
- Plate radiators mfg. Hudevad
- Plate radiators mfg. unknown
- Flanged radiators mfg. Eres
- Flanged radiators mfg. unknown
- Steel pipe ribs mfg. unknown

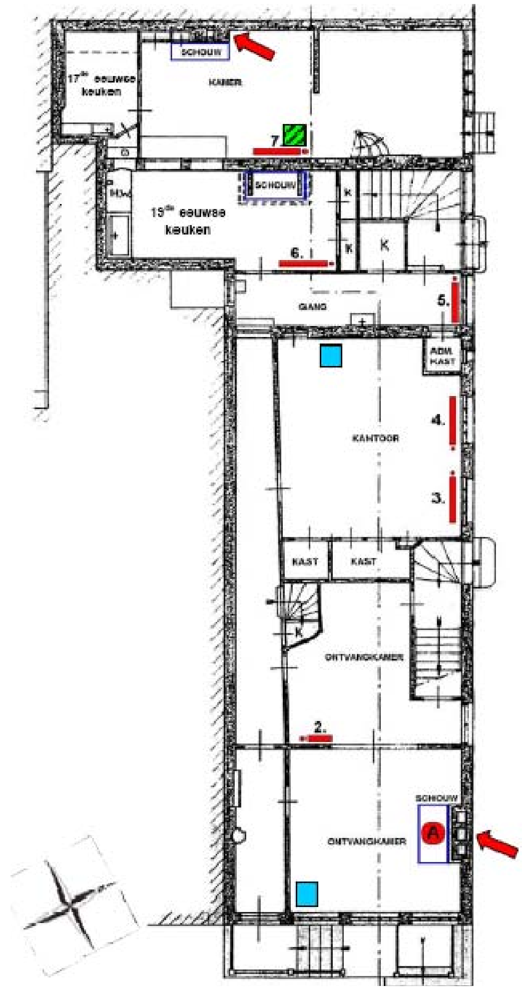
The structural floor plans below show the locations of the heating elements, gas stoves, chimneys, humidifiers and dehumidifiers.

CELLAR



[KEY:
CV-ketel = central heating boiler
CENTRALE VERWARMING = central heating
TOILETTEN = toilets
GARDE-ROBE = cloakroom
PUTJE = well]

GROUND FLOOR

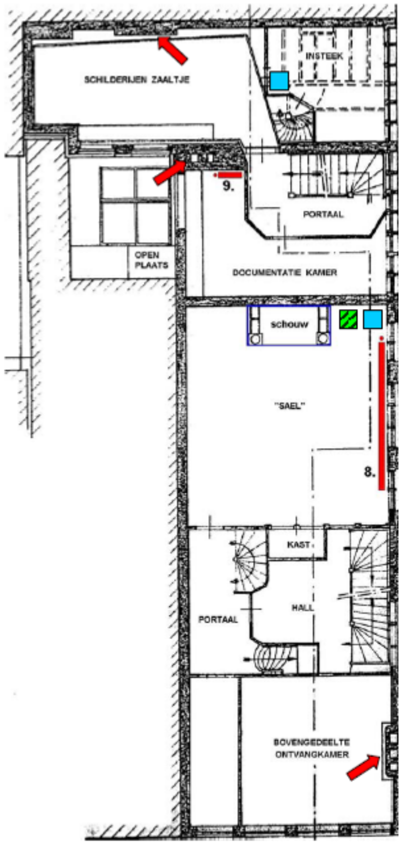


[KEY:
17de eeuwse keuken = 17th century kitchen
SCHOUW = chimney
KAMER = room
GANG = hallway
KANTOOR = office
KAST = cupboard
ONTVANGKAMER = reception room

Number	Type*	Dimensions h*l*w [mm]	Output [W]	Type of radiator valve
1	Plate radiator type 10	1000 x 800	980	Thermostatic, mfg. Danfoss
2	Plate radiator type 22	1800 x 580	3800	Thermostatic, mfg. Herz
3	Flanged radiator 30 vanes	450 x 1230 x 150	2100	Thermostatic, mfg. Danfoss
4	Flanged radiator 30 vanes	450 x 1230 x 150	2100	Thermostatic, mfg. Danfoss
5	Flanged radiator 25 vanes	450 x 1250 x 220	2350	Thermostatic, mfg. Danfoss
6	Veha Plate radiator type 20	1010 x 1090	2200	Thermostatic, mfg. Danfoss
7	Eres Flanged radiator 15 vanes	1080 x 620 x 100	1500	Thermostatic, mfg. Danfoss
A	Gas stove		9400	n.a.
* Type 10 = 1 plate radiator Type 20 = 2 plate radiator Type 22 = 2 plate radiator with 2 convectors		[blue square] = humidifier [green square] = dehumidifier ➚ = shaft location		

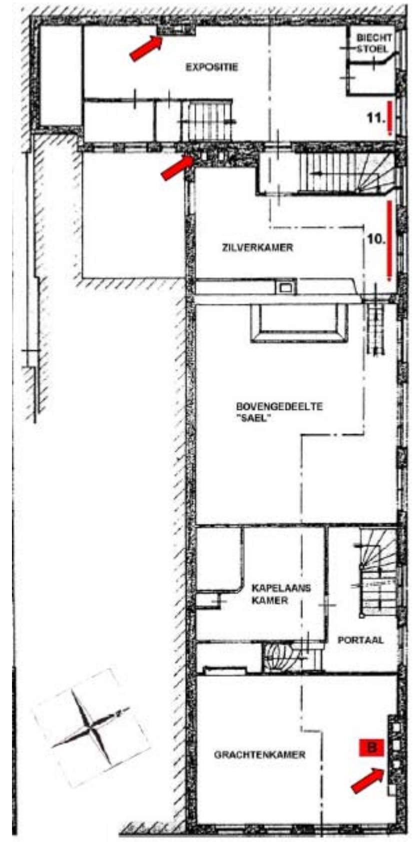
Figure 4 Floor plan of the cellar (1) and the ground floor with installed heating elements, humidifiers and a gas stove (A) in the reception room (Antechamber). The outputs of the installed radiators are given in the table with a 90/70/20°C water-supply/return/room temperature system. The outputs are estimated from data provided by the manufacturer or by comparison with similar products.

1st FLOOR



[KEY:
SCHILDERIJEN ZAALTJE = paintings exhibition room
INSTEEK = mezzanine
PORTAAL = Antechamber
DOCUMENTATIE KAMER = documents room
SCHOUW = chimney
KAST = cupboard
BOVENGEDEELTE ONTVANGKAMER = upper section reception room]

2nd FLOOR

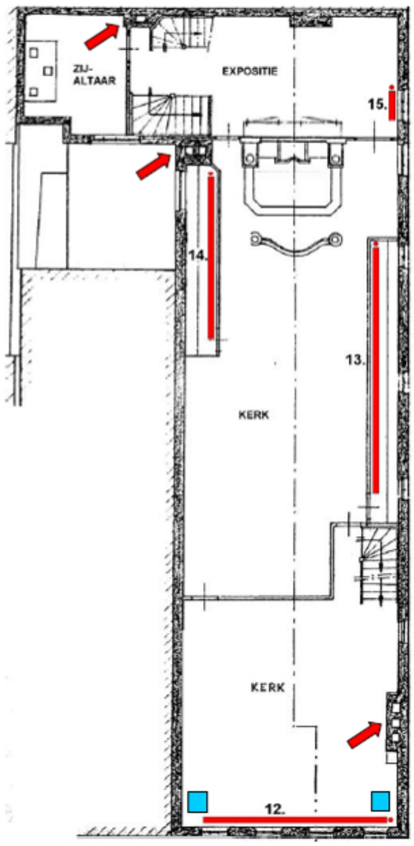


[KEY:
EXPOSITIE = exhibit
BIECHTSTOEL = confessional
ZILVERKAMER = silver room
BOVENGEDEELTE "SAEL" = upper section of Sael
KAPELAANS KAMER = Chaplain's room
GRACHTENKAMER = Canal room]

Number	Type*	Dimensions h*l*w [mm]	Output [W]	Type of radiator valve
8	Hudevad Plan plate radiator	600 x 3200 x 50	4400	Thermostatic, mfg. Heimeier
9	Flanged radiator 10 vanes	1000 x 400 x 220	1600	Thermostatic, mfg. Danfoss
10	Plate radiator type 21	400 x 2240	2950	Thermostatic, mfg. Danfoss
11	Flanged radiator 23 vanes	690 x 920 x 150	2250	Thermostatic, mfg. Danfoss
B	Gas stove		5600	n.a.
* Type 21 = 2 plate radiator with 1 convector		[blue square] = humidifier [green square] = dehumidifier ➚ = shaft location		

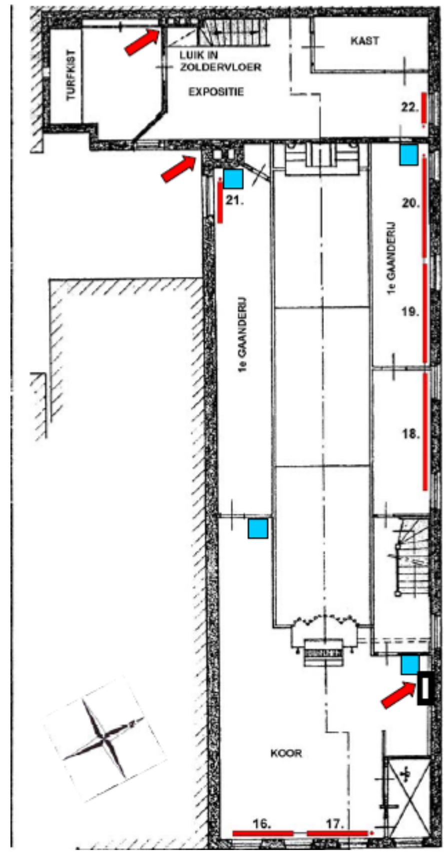
Figure 5 Floor plan of the 1st (1) and 2nd floors and the installed heating elements, humidifiers, dehumidifiers and gas stove (B) in the Canal room. The outputs of the installed radiators are given in the table with a 90/70/20°C water-supply/return/room temperature system. The outputs are estimated from data provided by the manufacturer or by comparison with similar products.

3rd FLOOR



[KEY:
ZIJ-ALTAAR = side altar [Lady chapel]
EXPOSITIE = exhibit
KERK = church

4th FLOOR

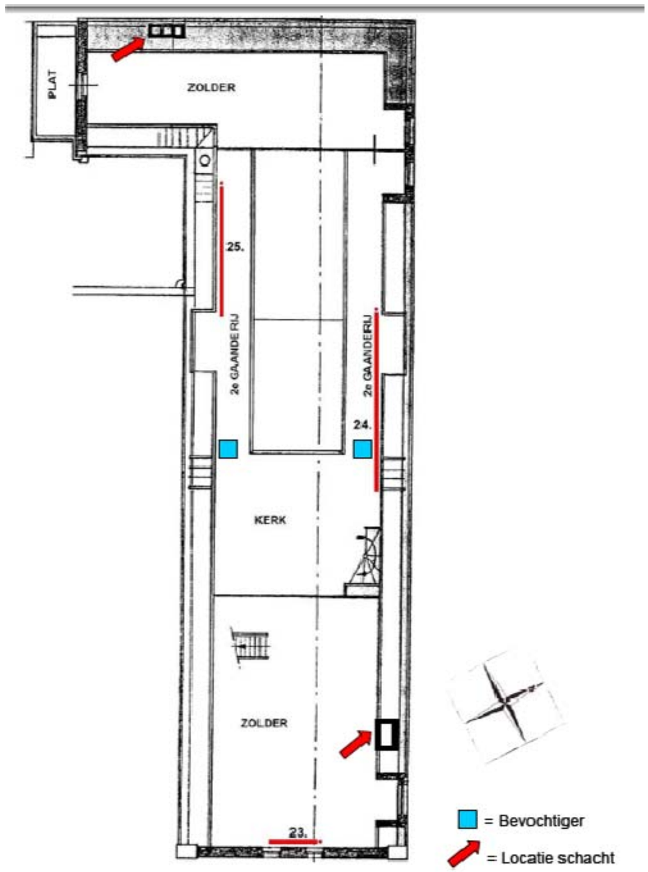


[KEY:
TURFKIST = peat chest
LUIK IN ZOLDERVLOER = trap door in attic floor
KAST = cupboard
GAANDERIJ = gallery
KOOR = choir

Number	Type*	Dimensions h*l*w [mm]	Output [W]	Type of radiator valve
12	Flanged radiator 100 vanes	600 x 4950 x 110	6900	Thermostatic, mfg. Danfoss
13	Steel pipe ribs	L = 7500 Ø= 110	3500	Thermostatic, mfg. Danfoss
14	Steel pipe ribs	L = 4450 Ø= 110	2100	Thermostatic, mfg. Danfoss
15	Flanged radiator 21 vanes	680 X 900 X 150	1700	Thermostatic, mfg. Danfoss
16	Plate radiator type 20	500 X 1600	1800	Thermostatic, mfg. Danfoss
17	Plate radiator type 20	500 X 1600	1400	Connected to radiator No. 16
18	Veha Plate radiator type 10	285 X 3310	1000	Connected to radiator No. 19
19	Veha Plate radiator type 10	285 X 2950	800	Connected to radiator No. 20
20	Veha Plate radiator type 10	285 X 2950	1000	Thermostatic, mfg. Danfoss
21	Plate radiator type 20	600 X 1280	1700	Thermostatic, mfg. Danfoss
22	Flanged radiator 19 vanes	690 X 750 X 150	1600	Thermostatic, mfg. Danfoss
* Type 10 = 1 plate radiator Type 20 = 2 plate radiator		[symbol] = humidifier [symbol] = dehumidifier ➚ = shaft location		

Figure 6 Floor plan of the 3rd and 4th stories with the installed heating elements and humidifiers. The outputs of the installed radiators are given in the table with a 90/70/20°C water-supply/return/room temperature system. The outputs are estimated from data provided by the manufacturer or by comparison with similar products.

5th FLOOR



[KEY:
PLAT = plan
ZOLDER = attic
GAANDERIJ = gallery
KERK = church]

[blue square] = humidifier ➚ = shaft location

Number	Type*	Dimensions **h*l*w** [mm]	Output [W]	Type of radiator valve
23	Plate radiator type 10	600 x 1830	5700	Thermostatic, mfg. Danfoss
24	Steel pipe ribs	L = 5500 Ø= 110	2500	Thermostatic, mfg. Danfoss
25	Steel pipe ribs	L = 4100 Ø= 110	1900	Thermostatic, mfg. Danfoss
* Type 33 = 3 plate radiator and 3 convectors				

Figure 7 Floor plan of the 5th floor with the installed heating elements and humidifiers. The outputs of the installed radiators are given in the table with a 90/70/20°C water-supply/return/room temperature system. The outputs are estimated from data provided by the manufacturer or by comparison with similar products.

Central heating boiler

The central heating boiler is located in the furnace room on Heintje Hoeksteeg [the alley]. This provides the warm water for the radiators for the museum and the premises at No. 26, which belong to the museum and serve as office and storage space.

Data:
- Remeha type Gas 3C
- 7 sections
- closed system
- nominal output 138 kW
- year of manufacture 1991

The air comes in via a grate in the door to the furnace room. The flu gases are removed via a flu gas duct which exits the roof. Furthermore, the storage area is provided with a gas detection system with 3 sensors, mfg. Bieler & Lang type LS 7014-2.

Figure 8 Central heating boiler Remeha Gas 3C.

Control

The central heating boiler is turned on/off by switches, controlled by a weather-dependent control thermostat (see user's guide in Appendix A), which is mounted in the switch box of the furnace room. The settings of this control thermostat are:

Correction daytime temp: 0.5 K
Night-time lowering : 4 K
Feed line : Outside temperature -5°C → feedwater temperature 80°C
: Outside temperature 15°C → feedwater temperature 50°C
Modulating switch : Continuous normal functioning

A temperature sensor has been placed on the outside wall for weather compensating temperature control. The weather-dependent thermostat will increase the water temperature in the central heating boiler when the outside temperature is lower.
On the 3rd floor south wall of the church, two room thermostats have been installed. One of them is set at 23 °C. According to the installer these are no longer connected to the central heating system boiler, which is regulated entirely by the weather. A finer room temperature adjustment occurs via thermostatic radiator valves.

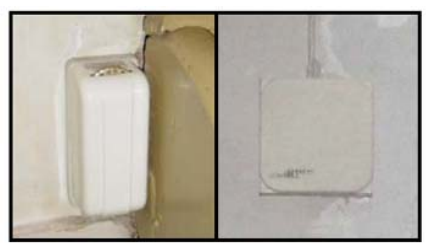


Figure 9 Room thermostats in the Church

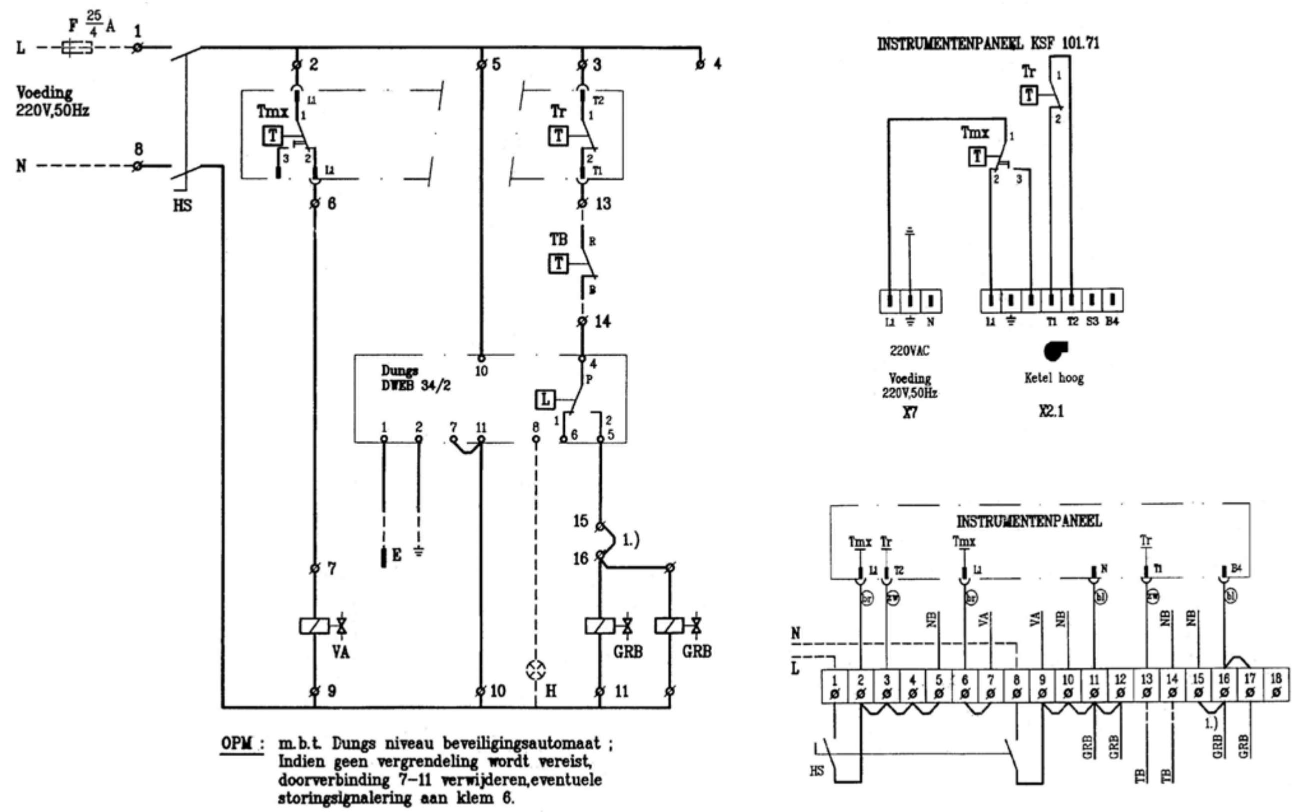
There is also a 3rd room temperature sensor mounted in the building, which is for safeguarding the building temperature. This sensor has a readable display and is located at the Heintje Hoeksteeg entrance. According to the installer, if the temperature drops too low (<16°C), this sensor sends a signal to a control center which will then contact the installer by telephone.

Switch box

Figure 10 The switch box closed (l) and open, with the components numbered.

The switch box in the furnace room has the following components:
1. Main switch
2. Alarm signal indicator
3. Landis&Gyr RHL 46 weather compensated boiler control, manufactured in 1991
4. Waste water pump switch
5. Clamp rail
6. Automatic controls
7. Bieler & Lang LS 7014-2 gas detection apparatus
8. Magnetic switch for thermal safety pump
9. Relay switch for technical trouble

Control schematic



[Key:
Voeding = feed
m.b.t. [met betrekking tot] = relative to
Dungs niveau beveiligingsautomaat = Dungs safety level automatic switch.
Indien geen vergrendeling words vereist, doorverbinding 7-11 verwijderen, eventuele storingsignalering aan klem 6. = If no lock-out is required, remove the 7-11 bridge; any problems signaled on clamp 6.
Ketel boog = boiler bridge
*INSTRUMENTENPANEE*L = instrument panel

Figure 11 The control schematic of the central heating boiler. According to the installer, the Tmx (maximum safe temperature) and Tr (room thermostat) are no longer connected and the building is entirely regulated by the weather.

3. Portable humidifiers and dehumidifiers

There are dehumidifiers and humidifiers located at various locations in the museum. These locations are essentially fixed; a humidifier or dehumidifier is moved only occasionally, for example when there is a change in exhibits.

Figure 12 The dehumidifier and humidifier units used in the Sael.

Types of humidifiers and dehumidifiers

Humidifiers
The humidifier units also have activated charcoal air filters. The humidifiers are set for 50% RH. The capacity settings are set at III in the winter and I in the summer.

Data: Mfg. Defensor type P14 portable cold evaporator air humidifier

Capacity settings	I	II	III
Humidifying capacity [l/h]	0.5	0.7	0.9
Air exchange [m^3/h]	180	280	360

Volume of water reservoir 2x10 l.
Energy consumption max. 55 W.

Dehumidifiers

The dehumidifiers are set at 50% and work on the principle of cool drying with subsequent heating by the condenser.

Data: Mfg. Trion type Dry care Dehumidifier

Data for room conditions:	10°C/80%	°C/80%
Dehumidifying capacity [l/h]	0.125	0.250
Power used [W]	275	330

Volume of water reservoir 8 l.

Locations

For the locations of the humidifiers and dehumidifiers, see figures 3 through 6.

Table 1 Locations of the Dehumidifier and humidifier units in the museum.

Location	Humidifier	Dehumidifier
Antechamber	1	
Office	1	
Sael	1	
Church 3rd floor	2	1
Church 1st gallery	2	
Church 2nd gallery	2	
Choir (at the organ)	2	
Paintings room	1	
Room 19th century kitchen		1*

* Dehumidifier moved to paintings exhibit room on 08-12-05

4. Climate control requirements for preservation

Visitors and personnel should be comfortable in the Amstelkring Museum. In general, the climate (T, RH) which is suitable for preserving the building and its interior falls within a more narrow range than the climate in which people feel comfortable., The following list of requirements was prepared, based on reserach carried out by various professional organizations:

Comfortable indoor climate for people [2]:

-the desired RH in the rooms should fall between 25% and 65%

-the desired temperature in the rooms should fall between 17°C and 26°C (depending on the season)

Recommended indoor climate for preserving a (mixed) collection and interior, as per:

• *Instituut Collectie Nederland* [Netherlands Institute for Cultural Heritage] [3]:

-the desired RH in the rooms should fall between 48% and 55%

-the desired temperature in the rooms should fall between 2°C and 25°C

-the maximum allowed RH-difference is 2% per hour and 3% per day.

-the maximum allowed temperature difference is 2°C per hour and 3°C per day.

• ASHRAE B [4]: precise regulation, small fluctuations and lower winter temperatures

-the desired RH in the rooms should fall between 40% and 60%

-the desired temperature in the rooms should fall between 15°C and 25°C

-the maximum allowed RH-difference is 10% per day.

-the maximum allowed temperature difference is 5 K per day.

• ASHRAE C [4]: would reduce the greatest risks to the building and the collection

-the desired RH in the rooms should fall between 25% and 75%

-the desired temperature in the rooms will not exceed 25 °C

Attainability of requirements

Given the Amstelkring Museum's monument status, and the limited possibilities of indoor air-conditioning, this report is based on the requirements of ASHRAE B.

5. Analysis of long-term measurements

The focus of the investigation of the Amstelkring Museum indoor climate was the temperature and relative humidity of the air. Measurements of temperature and relative humidity were taken at the following locations in the building:

- Behind the altar, 1st gallery
- Church under the Lamp of God - low
- Church under the Lamp of God - middle
- Church under the Lamp of God - high
- Church near the organ
- Sael
- Canal room
- Antechamber above the reception desk

Three measurements were made under the Lamp of God to measure the degree of temperature stratification and RH at different heights in the church. Outdoor measurements were also taken.
The relative humidity of the air in the proximity of a surface, which has a different temperature than the indoor air, diverges from the average relative humidity of the indoor air. Because of the danger of structural degradation and the degradation of objects hanging against the outside walls, a number of surface temperature measurements were taken at the following locations:

- Beam head in the vestment cupboard
- Church wall surface, north side
- Church window surface, north side
- Church window sill, north side

Next, the relative humidity of the air near the surface (φ_s) can be calculated by using the maximum vapor pressure at this air and surface temperature, and the relative humidity of the air in the room.

Illuminance was measured at one location, namely near the altar. Excessive light can be especially harmful to pigments in paints. Moreover, direct sunlight heats up an object, which can cause damage through drying, shrinking and expansion.

Boiler problems during the measuring period

The table below presents the boiler problems which occurred during the measuring period and were reported or noted down in the climate report forms. The boiler of the central heating system often shut off at night and was reset the following morning.

Table 2 Data showing boiler problems.

Date	Remarks
03-01-05 through 03-03-05	Boiler down
12-29-05	Heating system down during the night, re-started around 9 am
01-17-06	No heating in the morning

Results of temperature and relative humidity measurements

The results of the measurements for each location are given below. Appendix A presents the results for each measurement location versus time. The measured values are also given in a Mollier diagram and compared to the Ashrae B [4] climate requirements.

Behind the altar, 1st gallery

See Figure 35 in Appendix B. What is striking in this graph is the number of times that the temperature fell below 15°C during the measuring period. This indicates problems with the central heating boiler. See the figure below for a detail of one of these periods.

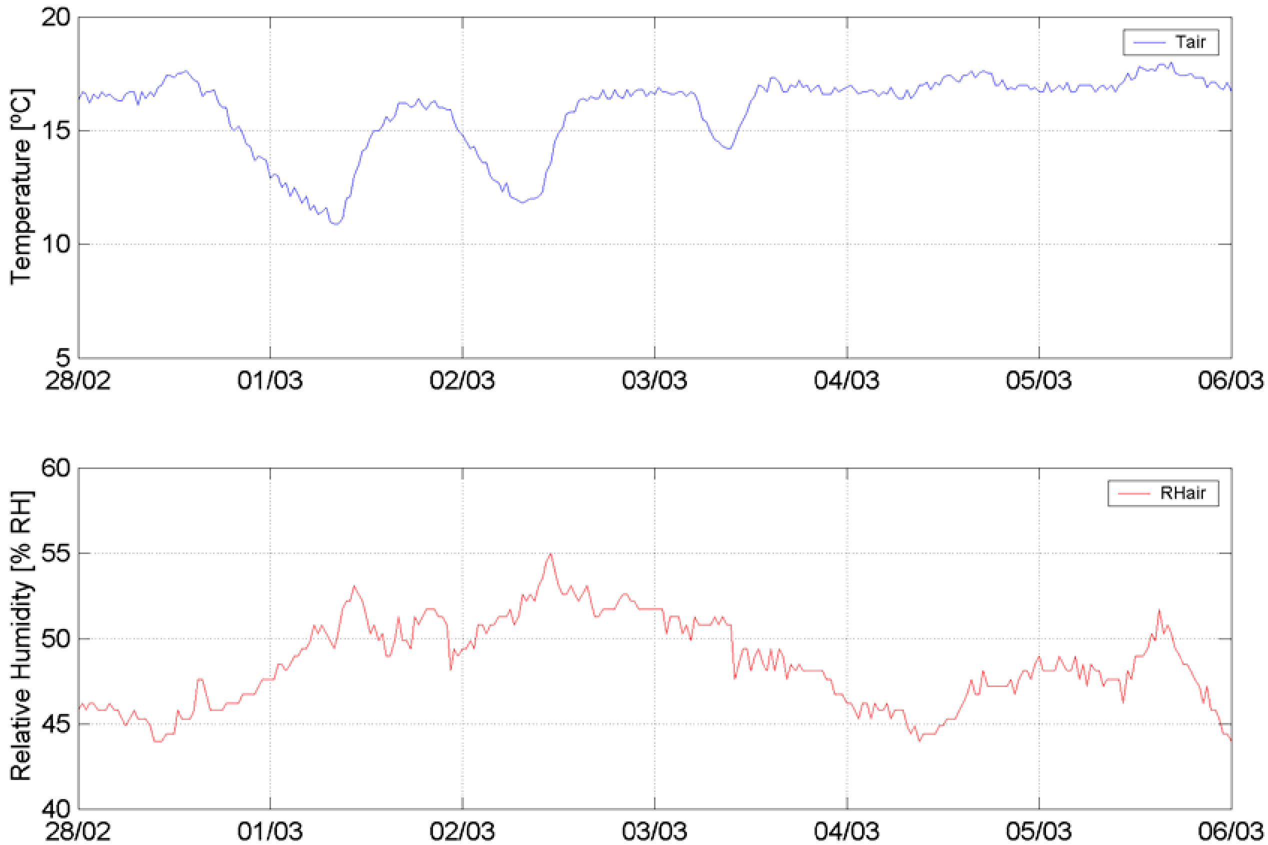


Figure 13 Record of the effect of central boiler problems on the indoor climate at the beginning of March. The resulting decline in temperatures led to fluctuations in the RH.

The Mollier diagram (see Figure 36 in Appendix A) shows that during the summer, 26% of the temperatures measured were higher than 25 °C.
The RH in the summer and autumn often exceeds the 60% limit, but does not exceed 70%.

Church

The readings used for the general analysis of the indoor climate in the church were taken from the middle sensor which is a component of the stratification measurements beneath the Lamp of God. See Figure 37 and Figure 38 in Appendix A for a graphic presentation of these measurements.
In August, unfortunately, some of the measurements were lost, possibly through problems with the sensor. The indoor climate in the church can be compared to the measurement values behind the altar in the 1st gallery. Namely, exceeding the temperature limit in the summer and slightly exceeding the RH in the summer and autumn.

Church near the organ

See Figure 39 and Figure 40 in Appendix B. In the summer, 23% of the temperature readings were higher than 25°C. The humidity of the air surrounding the organ occasionaly increased above 60% in the summer and autumn. There are no perceptible extreme fluctuations in T and RH.

Sael

See Figure 41 and Figure 42 in Appendix B. In the Sael, 13% of all summer readings were above 25°C with a maximum of 27.8°C.
In the autumn and primarily in the winter, the RH fell below the 40% line, 17% and 49% of the time, respectively, possibly as a result of the drying effect of the heating system.
RH-fluctuations per 24 hours quite often exceed 10%, especially in the autumn.

Canal room

See Figure 43 and Figure 44 in Appendix B. In the summer 32% of all the readings were above 25°C, possibly as a result of direct sunlight and the high number of visitors. The RH was quite low for a significant portion of the winter, between 30 and 40%, most probably because of the heating system and the low absolute moisture content of the indoor air. It can be seen that during the early autumn for example, the RH slightly exceeded the 60% line.

Antechamber above the reception desk

See Figure 45 and Figure 46 in Appendix B. In the summer, 26% of all the readings exceeded 25°C.
In the spring but primarily in the winter, the RH is often below 40%.
During the entire year, there were significant RH-fluctuations, more than 10 K per 24 hours, for 43% of all the 24-hour intervals during the measuring period.

Outside

See Figure 47 and Figure 48 in Appendix B. The sensor for the outside measurements probably received direct sunlight in the summer and therefore recorded too high a temperature. The RH-values are therefore probably also unreliable.

Surface measurements

Beam head in the vestment cupboard

See Figure 49 in Appendix B. This beam head was restored recently because of damage. During the measuring period, low surface temperatures were measured and the surface RH was usually above 70%. This means increased danger of microbial growth on the surface [4, 5].

Church wall surface, north side

See Figure 50 in Appendix B. The conditions at the surface of the outside wall do not represent an increased risk for mold during the measurement period since they are below the 70% line.

Figure 14 Two damaged areas on the window sills on the north-east wall of the Church resulting from surface condensation and high relative humidity at the surface.

Church window surface, north side

See Figure 51 in Appendix B. Condensation often forms as a result of the low surface temperatures of the single-pane glass in the winter and the high absolute humidity in the church. The consequences of this surface condensate for wooden window sills are clearly visible.

Church window sill, north side

See Figure 52 in Appendix B. During the measurement period, there were no potential mold problems found on the window sill surface.

Vertical stratification within the Church

Stratification measurements in the church were taken beneath the Lamp of God. Three T/RH-sensors were hung under this lamp to measure the temperature and the RH differences at various heights. The heights of the sensors above the floor were respectively 3, 6 and 8 meters. The figure below gives the differences in temperature and RH between the highest and the lowest sensor. In figure 53 in Appendix B, the data measured by the 2 sensors were plotted against each other. From the analysis of the graphs, it appears that the vertical thermal stratification in the church is minimal and amounts to only a few degrees.

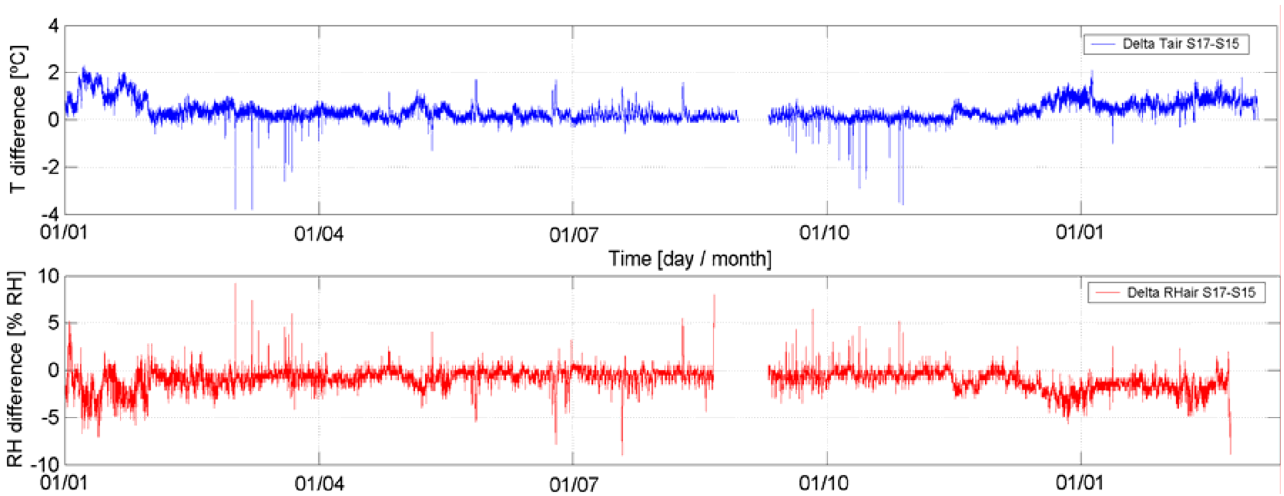


Figure 15 The top graph gives the temperature difference between the highest and the lowest sensor. The lower graph gives the difference in relative humidity. Unfortunately, possibly due to a defective sensor, a portion of the measurements was not recorded. From the graphs it is clear that the vertical thermal and RH stratification in the church is minimal.

Illuminance

The measurement of illuminance shows that the sensor which was mounted near the altar was often struck by direct sunlight. The desired Lux quantity for museums should lie between 50 – 250 lux [3]. Only from May to August did the value lie below 250 Lux, see the figure below.

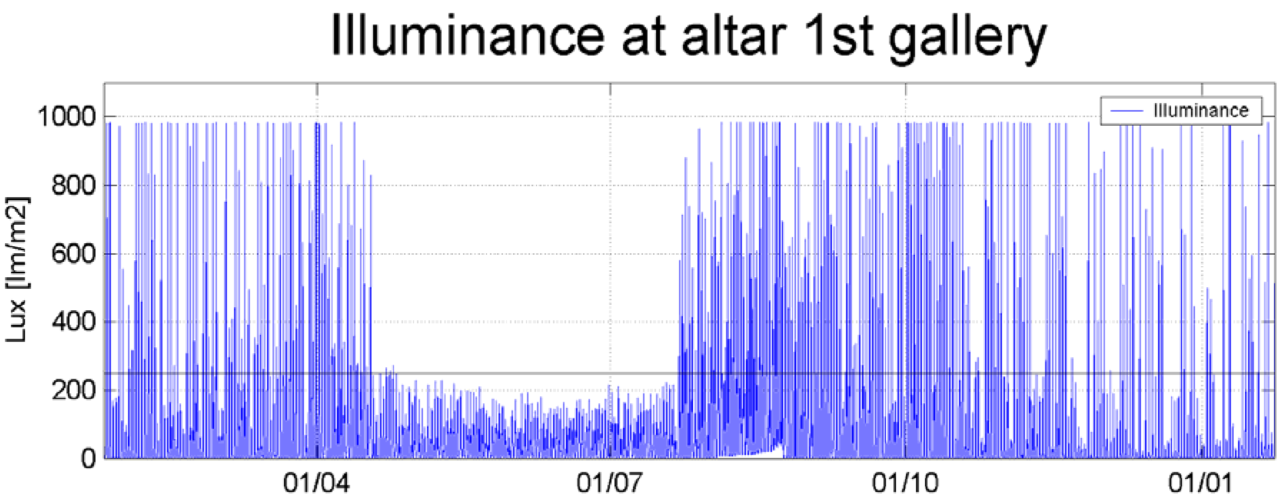


Figure 16 Due to direct sunlight, very high Lux values were measured up to the end of May and after the beginning of August. From the end of May through the beginning of August the sun was probably so high that no direct sunlight would fall on the sensor. The Lux quantities during this period were acceptable. The reason for the flattening of the values just under 1000 Lux is that the range of the sensor is from 0-1000 Lux. The sensor detected light during the night in the areas marked by the red arrow, possibly because of a lighted outside stairway.

Exceeding 250 Lux is acceptable, depending on the length of time that this was exceeded. The figure below gives the figures for the first six days of April. From this figure it can be seen that the limit was exceeded for several hours with an intensity of 1000 Lux.

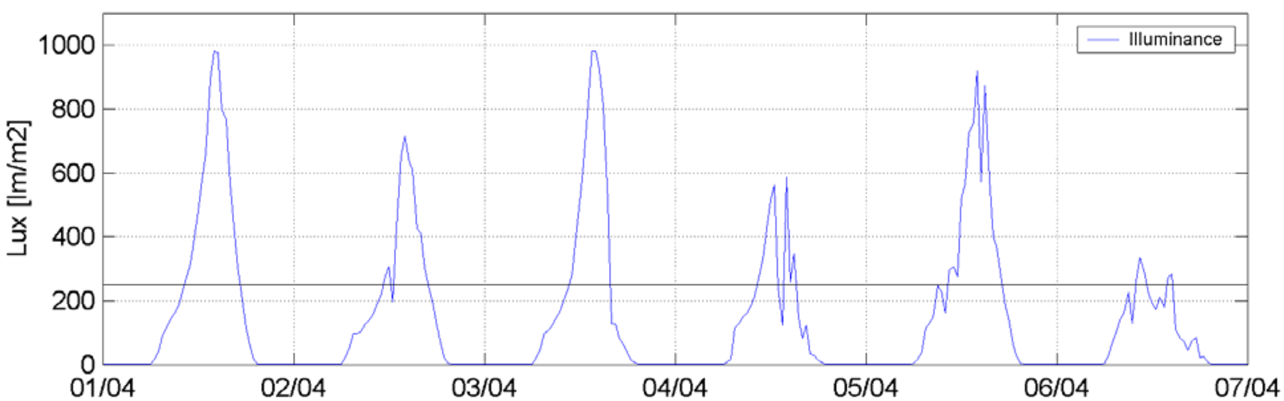


Figure 17 The results of the Lux measurements for the first week of April. The day-night rhythm is clearly visible, where during the day the maximum desirable quantity of 250 Lux is amply exceeded for a substantial length of time, except on cloudy days.

6. Influence of visitors on the indoor climate

A record was kept from April 12, 2005 of the number of visitors and special events.

The museum hours are: Monday through Saturday 10:00 am - 5:00 pm
Sundays and holidays 1:00 pm - 5:00 pm
Closed January 1 and April 30

The number of visitors to the museum and the time were recorded daily, and a record was also kept of the numbers of people attending special events such as weddings. The figure below presents the number of visitors per day for the period of April 12, 2005 through April 23, 2006.

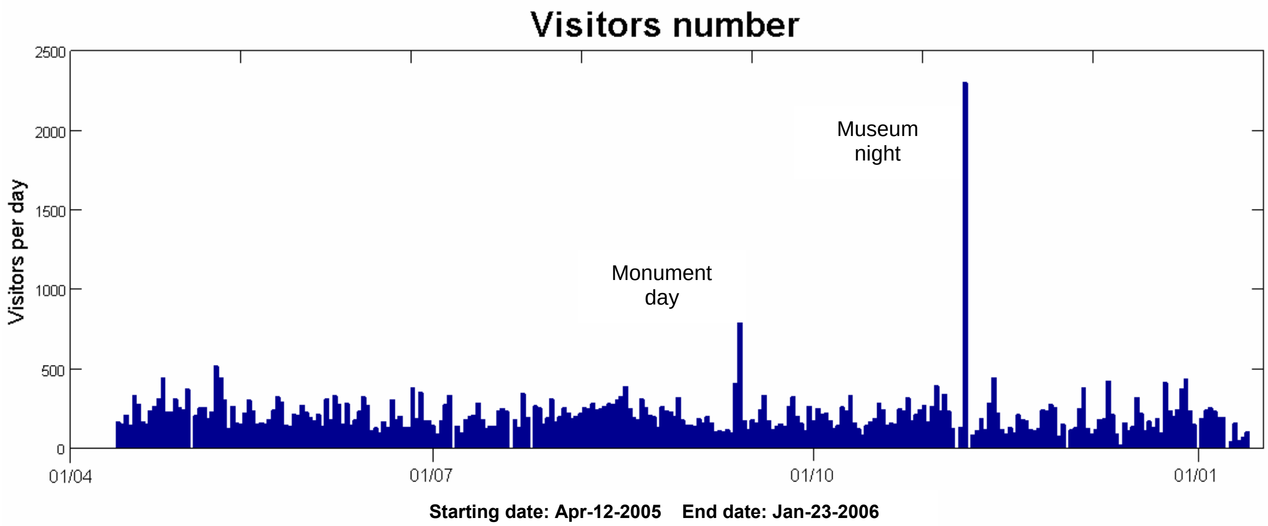


Figure 18 This graph records the total number of visitors per day for the period of April 12, 2005 through January 23, 2006. Obvious spikes are on September 11, Monument Day and on November 5th, Museum Night. For some days no data is available.

To estimate the number of visitors per normal business hour, we took the total number of visitors on that day, minus the number of visitors for any event, divided by the number of normal business hours for that day. The total number of visitors attending events is also given. See Figure 19 for a graphic presentation of the results. Since events almost always take place in the Church, this graph gives a good picture of the number of visitors to the Church per hour.

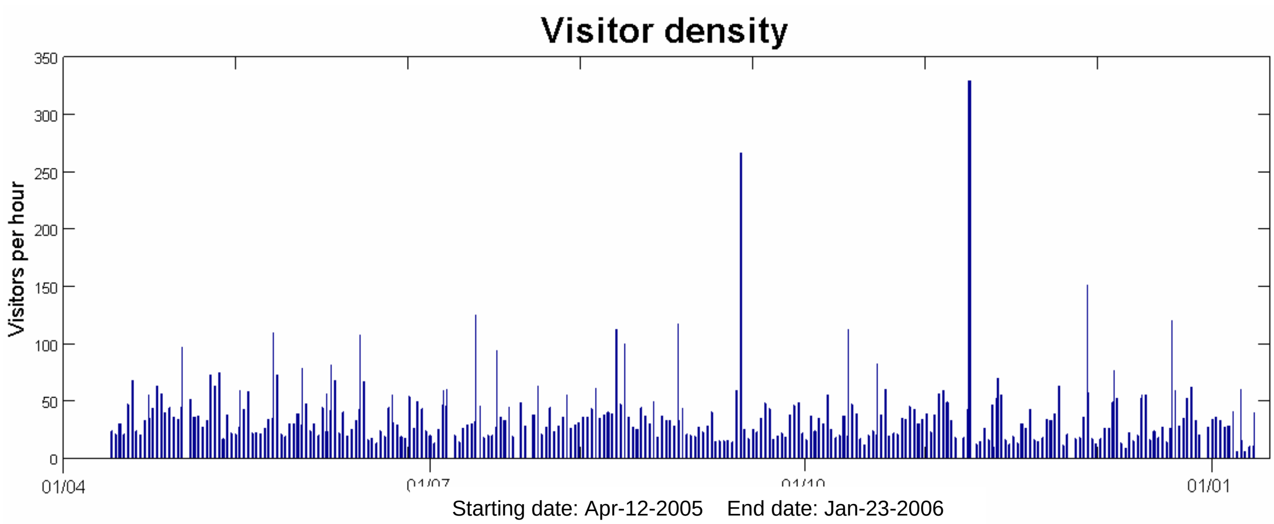


Figure 19 This graph records an estimate of the average number of visitors per business hour for the period of April 12, 2005 through January 23, 2006. In this way events are clearly noted as spikes in the graph.

Table 3 gives the points in time during which there were events in the museum, such as weddings. The events take place in the Church and occasionally in the Sael.

Table 3 Events in the Amstelkring museum

Date	Time	Location	Event	Number of persons
04-21-05	11:00-12:00		Tour	55
04-29-05	14:00-15:00	Church	Wedding	97
05-13-05	16:00-17:00		Tour	59
05-21-05	14:30-15:30	Church	Wedding	110
05-28-05	14:00-16:00	Church	Wedding	79
06-03-05	14:00-16:00	Church	Wedding	56
06-04-05	15:00-16:00	Church	Wedding	81
06-11-05	12:30-14:30	Church	Wedding	108
06-19-05	10:30-13:00	Church	Reading	55
07-01-05	13:00-15:00	Church	Wedding	47
07-01-05	16:00-17:00		Tour	59
07-02-05	11:00-12:00	Church	Concert	60
07-09-05	14:00-16:00	Church	Wedding	125
07-14-05	14:00-16:00	Church	Wedding	94
08-06-05	11:00-11:30	Church	Concert	41
08-12-05	13:30-15:30	Church	Wedding	113
08-14-05	14:00-15:00		Tour	100
08-27-05	13:00-14:00	Church	Wedding	117
09-11-05	13:00-17:00		Open Monument Day	1064
10-07-05	16:00-18:30	Church	Wedding	113
10-14-05	14:00-16:00	Church	Wedding	83
10-15-05	14:00-14:20	Sael	Wedding	34
11-05-05	19:00-02:00		Museum Night	2300
11-11-05	15:30-17:00	Sael	Wedding	25
11-11-05	18:00-20:00	Sael	Dinner	10
11-12-05	18:00-19:30	Church	Reception reading	70
12-04-05	12:00-13:00	Church	Artists mass	151
12-10-05	19:30-20:30	Church	Wedding	76
12-17-05	13:30-15:30	Church	Wedding	55
12-24-05	20:00-21:00	Church	Christmas Eve mass	120
12-24-05	22:00-23:00	Church	Christmas Eve mass	110
01-10-06	13:00-14:00	Church	Reading and concert	60
01-13-06	16:00-17:00	Church	Reading	40

People produce moisture. This moisture is absorbed into the air, which means that the absolute moisture content can increase rapidly during events.
During events which have a large number of visitors, the influence on indoor climate is clearly noticeable. Namely, during cold weather the RH near cold surfaces increases sharply, and sometimes condensation is formed.
The graph of Figure 20 records the RH of the glass in the church and an estimate of the number of persons visiting per hour for the period of August 20 to December 28, 2005. As time goes on and the outside climate becomes colder, the surface temperature of the glass decreases. This causes more frequent condensation.

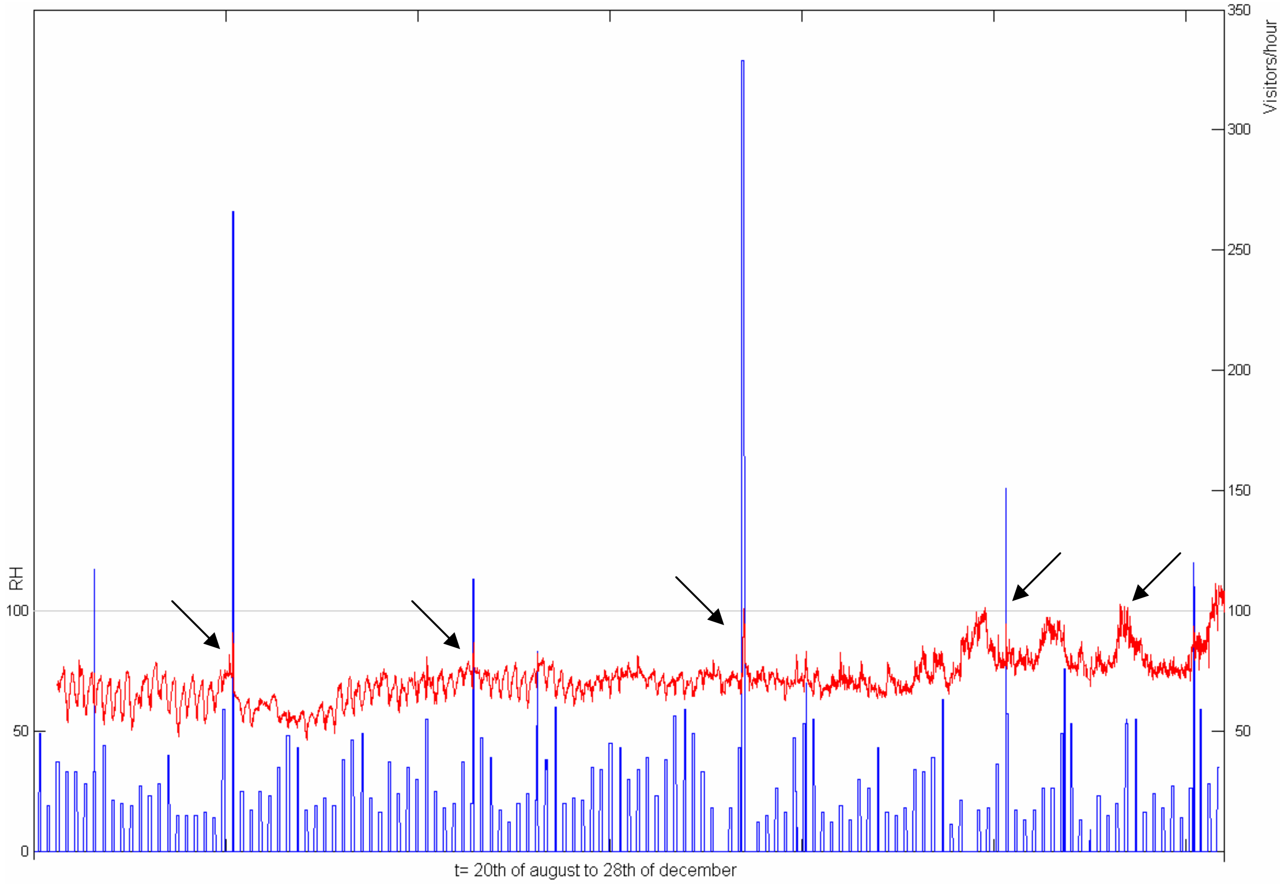


Figure 20 This figure shows the connection between a high number of visitors and condensation on the glass surfaces in the Church. The estimated number of visitors per hour (blue line) is plotted against the RH obtained by measuring the glass surfaces in the Church. The arrows indicate a number of cases where the RH rises sharply during the presence of a large number of visitors. Condensation often occurs during cold weather when there are a large number of visitors. This can be seen when the red RH line reaches 100% or higher.

7. Infrared thermography

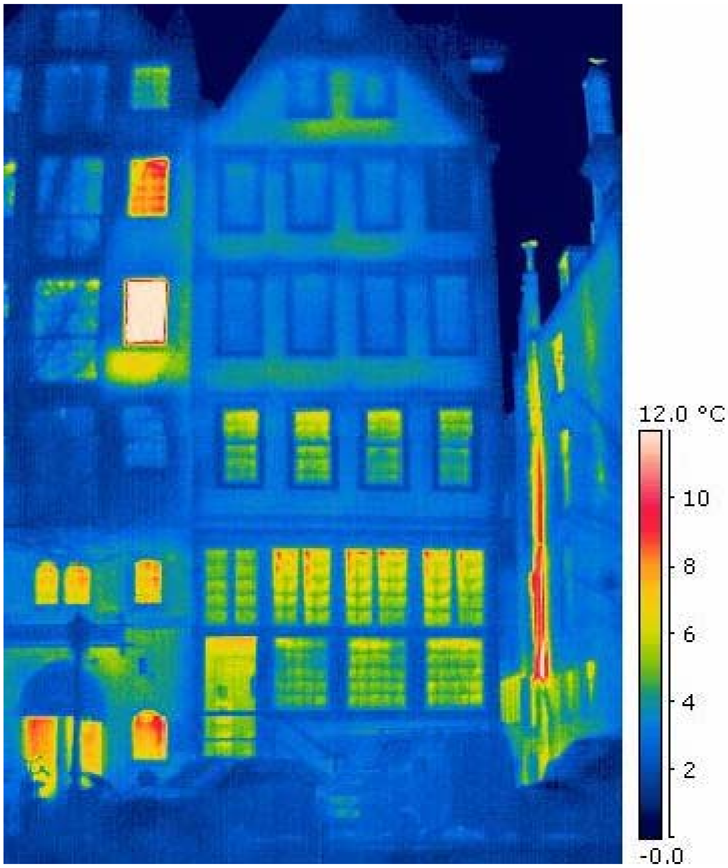


Figure 21. A thermographic record of the front wall of the Amstelkring Museum. The cold surfaces in the photograph are dark. The warmer surfaces, such as the glass, are lighter.

General

Infrared thermography is a technique which uses a special camera to create infrared images to visualize the thermal energy radiated by an object. Thermal energy, or infrared energy, is light which is not visible because the wavelength is too long to be perceived by the human eye. It is the part of the electromagnetic spectrum which we perceive as heat. Everything which is warmer than absolute zero radiates heat. The higher the temperature of the object, the more the infrared radiation radiated. Infrared thermography makes it possible to measure temperature very precisely without contact.

The relative humidity of the air near the surface (φ_s) can subsequently be calculated using the maximum vapor pressure for the air and surface temperature and the relative humidity of the air in the room:

$$\varphi_s = \frac{\varphi_a \cdot p_{sat\,(Ta)}}{p_{sat\,(Ts)}}$$

Where φ_s = the relative humidity of the air near the surface [-]
$p_{sat\,(Ta)}$ = maximum vapor pressure of the air [Pa]
φ_a = relative humidity of the air [-]
$p_{sat\,(Ts)}$ = maximum vapor pressure near the surface [Pa]

On January 5, 2006 infrared measurements were taken in the Amstelkring Museum**.** Below, 5 interesting situations found on that day are discussed. The relevant images are presented in Appendix C.

Situation 1: Single-pane glass with condensation

See Figure 54 in Appendix C which shows the condition of the window on the north wall, where condensation on the glass can be easily seen. The surface temperature of the coldest parts of the glass is about 4°C. Since this is below the dew-point temperature of the indoor air, condensation will form.

Situation 2: Painting against a cold wall and surface condensation on the window sill

See Figure 55 in Appendix C. This painting is hung on an outside wall. The RH at the wall near the painting is approximately 70%. Behind the painting, the RH is probably even higher because of decreased airflow. There is condensation on some of the glass and the window sill.

Situation 3: Painting hanging on a cold outside wall

See Figure 56 in Appendix C. This painting is also hung on an outside wall. The photographs clearly show where the division is between the outside wall and the inner wall. In the vicinity of the painting the RH is approximately 70%, which could be even higher behind the painting due to the lower temperature.

Situation 4: Art object against cold outside wall

See Figure 57 in Appendix C. At the point that the art object touches the wall, the RH exceeds 70%, which could be even higher behind the object due to lower temperature.

Situation 5: Restored beam head

See Figure 58 in Appendix C. This regards readings of a recently restored beam head. The low surface temperatures at the wall-joint are clearly visible. During the conditions indoors at the time the photograph was taken, the maximum RH at the surface of the beam head was about 80%. This high RH value means a higher risk of microbial growth and condensation on the beam head, which can lead to its rotting away. Because the temperatures inside the wall are probably lower still, it is quite possible that there will be condensation inside the wall where the beam head is located.

8. Ventilation

The current ventilation system

The air exchange occurs via air infiltration and exfiltration through cracks and gaps or by opening windows and doors. This is not a good option for controlling the air quality. The air which comes in from outside is of an unfiltered quality: relatively dirty outside air is allowed to enter the museum. From the standpoint of the heating system, this is also a bad way to ventilate a building, particularly in the winter.
The floors are primarily made from planks between which there are many cracks. Where the ceiling is not finished with stucco, this results in a mutual vertical air exchange between the rooms.

Ventilation problems

The following difficulties or problems in the museum can be blamed on inadequate ventilation of the building [1]:

- CO_2 concentration too high
- stuff in the summer

The technical measures which might be taken to change the parameters related to these problems could include installing an adequate ventilation system.

Air exchange rate measurement

Method

The tracer gas method was used (sulfur hexafluoride, SF6) to determine the rate of air exchange in the church. Determining the rate of air exchange is an instantaneous measurement. The results of the measurement depend on different factors, such as the wind attack on the wall. The tracer gas is an inactive substance (in a chemical and biological sense) whose solubility and dispersion behavior is similar to that of the air. Bringing a quantity of SF6 into a room results in air having a certain concentration of SF6. By recording the reduced amounts of tracer gas over time, the air exchange rate of a room can be determined using the following formula:

$$n = \frac{\ln C_o - \ln C_1}{t}$$

Where n = air exchange [h^{-1}]
C_o = the concentration at a particular point of time 0 [ppm]
C_1 = the concentration at a particular point of time 1 [ppm]
t = time [h]

The gas was released virtually simultaneously at 2 ground level locations in the Church: once in front of the altar and once in the back of the Church under the organ. The SF6 gas concentration in the air was then measured at 5 different locations (see Figure 22). Other measurements were made in 3 locations in the Church and on the 3rd floor behind the altar. Measurements were also made in the Sael to see if there was any air flow from the Church into the Sael.
By fitting a curve to the data obtained (see Figure 23), and using the Matlab computer program, an equation was found with which the air exchange rate could be determined.

Results

Because an increase of tracer gas was measured in the air of the Sael, it can be concluded that there is an air current from the Church into the Sael. This could be via the stairwell, but also through spaces in the Church floor.

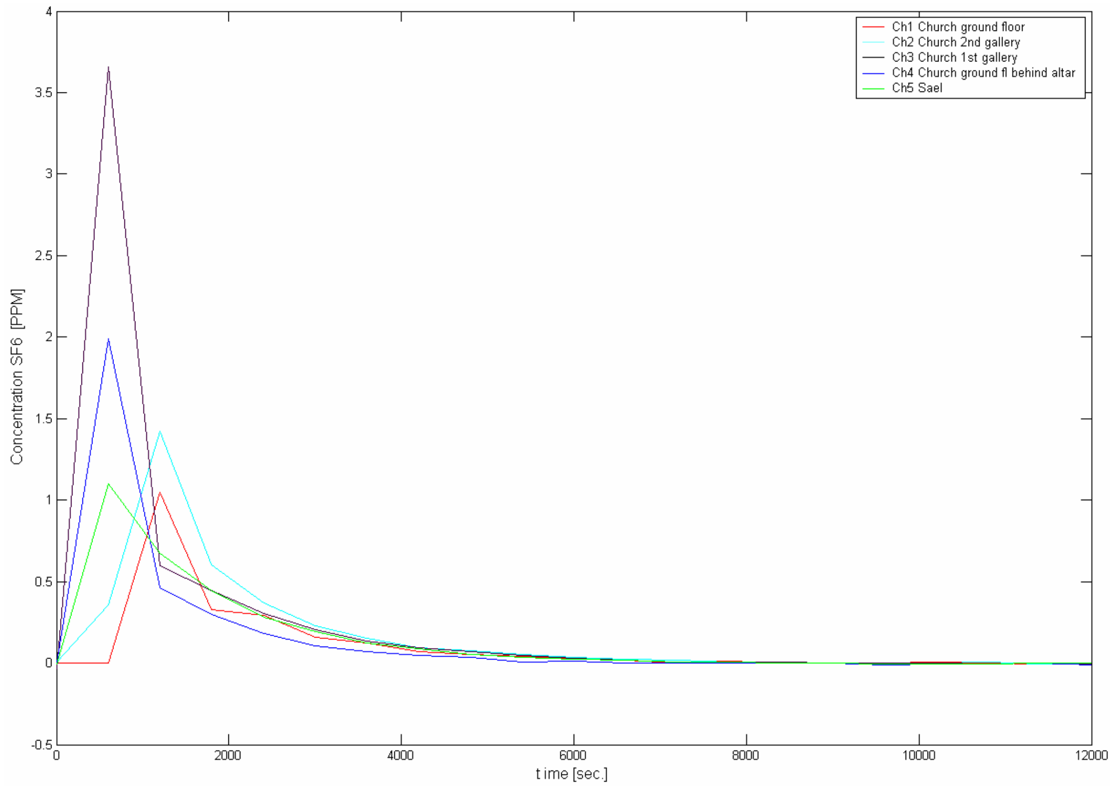


Figure 22 The measured values of the duct 1 through 5 versus time.

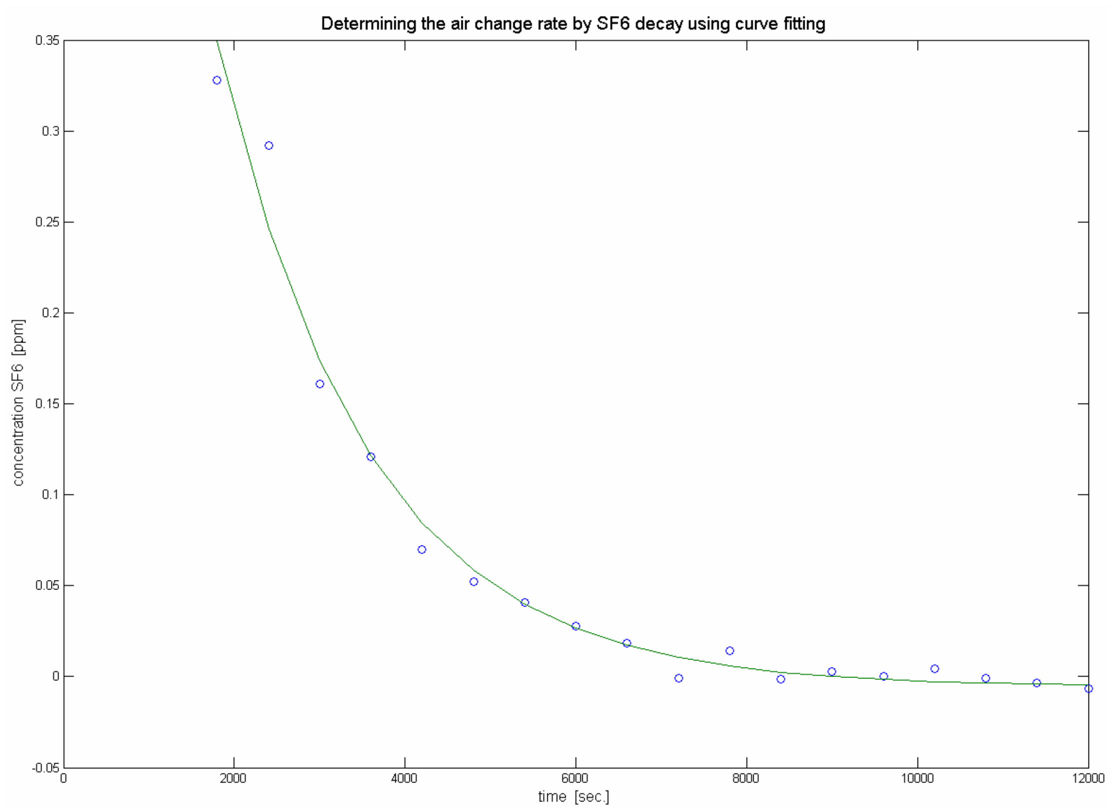


Figure 23 This graph shows the fitted curve as a solid line. The measured values are shown by circles. This example is for the measurements of duct 1.

The air exchange rates are given in the table below for the measuring locations in the Church. These values are fairly low, which is logical for a building without ventilation.

Table 4 Air exchanges detected at the measuring locations in the Church

Canal	Location	Air exchange [h^{-1}]
1	Third floor in church	0.21
2	2nd Gallery at the banister	0.27
3	1st Gallery at the banister	0.27

Desired ventilation

If a ventilation system is implemented in the building, the following requirements must be taken into account:

- filtered incoming air → for insects, soot particles/dust and biological agents
- adequate ventilation → to such degree that fewer problems occur
- mounting with minimal impact on the structure → given its status as a historic monument
- minimal visual impact on the interior → everything to be installed out of sight to the extent possible
- prevent in- and exfiltration increase → danger of indoor condensation

Capacity requirements

Building Code

The Building Code [7] paragraphs 3.10.2 article 3.56 prescribes that pursuant to NEN 8087, a device for changing meeting room air must have a capacity of at least 0.6 dm³/s per m^2. Table 2 shows the resulting figures for the museum's main room.

Arbo guidelines

The Arbo [*arbeidsomstandigheden* – on-the-job health and safety] guidelines [8] describe that the ventilating air must enter the room without causing a draft. The air exchange must occur in such a way that there is good circulation through the room. In rooms where light work is being done, the air exchange rate should be a minimum of 25 m³ /h per person.
As a guideline for the permitted CO_2 concentration in indoor air, the Arbo prescribe the following:

- a good quality of indoor air contains less than 1000 ppm CO_2
- the limit value for CO_2 is 1200 ppm

The Arbo guidelines are based on situations where people are continuously exposed to CO_2 concentrations while at work; however, they are given here in the context of this investigation as a useful indication for the required rate of ventilation.

Ventilation requirements with regard to combustion air

Separate circulation requirements hold for the two rooms in the building where there are gas stoves installed, for which specifically, the Building Regulations paragraph 3.13.2 table 3.89 are to be applied, which require that per NEN 8087 these rooms must have a ventilation capacity of at least 0.78×10^{-3} m³ /s per kW of nominal load. For the Antechamber this means 26 m³/h and for the Canal room 16 m³/h. Given that these values are so low, we must assume that the ventilation capacity requirements should be determined by the number of persons present.

Table 5 Recommended minimum required ventilation rates for the major rooms of the museum on the basis of the guidelines prescribed by NEN and Arbo.

Room	Floor surface[1] area [m^2]	Volume[1] [m^3]	Ventilation rate [m^3/h]			
			NEN8087[2]	W [h^{-1}]	Arbo[3]	W [h^{-1}]
Sael	35	290	76	0.4	250	1.3
Canal room	27.6	80	60	0.75	175	2.2
Church	225	900	486	0.54	2500	2.8

1 approximate
2 pursuant to NEN 8087: 0.0006 m³ per second per square meter
3. pursuant to Arbo: 25 m³ per hour per person. Calculated for the Sael: 10 persons, Canal room: 7 persons, Church: 100 persons.

Table 5 shows that the calculated ventilation quantities according to the Arbo guidelines lie much higher than those of the NEN 8087. Using a first-order differential comparison, it is possible to calculate the time it takes to reach a certain CO_2 concentration. This formula reads as follows:

$$t = \frac{L}{V} \ln \frac{G}{G + V\,(c_a - c_t)}$$

where: t = the time after the beginning of the CO_2 production and ventilation [h]
L = the volume of living space per person [m^3]
V = the ventilation per person per hour
G = CO_2 production per person
c_a = concentration of CO_2 in the atmosphere
c_t = concentration of CO_2 at any particular point in time

The table below shows the calculations for the amount of ventilation required so that, given a certain number of people in the room, the carbon dioxide concentration will not exceed 1200 ppm.

Table 6 Recommended required ventilation rates in the major rooms of the museum, calculated on the basis of maximum allowable CO_2 concentrations of 1200 ppm.

Room	Floor surface[1] area [m^2]	Volume[1] [m^3]	Number of people	Ventilation rate [m^3/h]	W [h^{-1}]
Sael	35	290	10	230	1.2
Canal room	27.6	80	7	165	2.1
Church	225	900	100	2160	2.4

1 approximate
2 assuming that after 8 hours, the CO_2 concentration for the Sael and the Canal room may not exceed 1200 ppm
3 assuming that after 1 hour, the CO_2 concentration for the Church may not exceed 1200 ppm

The calculated ventilation rates in Table 6 lie somewhat below the ones based on the Arbo guidelines given in Table 5. The Table 5 guidelines are recommended, provided that this can be done without creating drafts.

9. Ductwork

When dealing with insufficient ventilation, various options for improvement are available. Since this building is classified as an historic monument, it is preferable to use existing openings in the building to run the ductwork.

Storage room and ventilation equipment

Space is available in the building attic which can be used as storage space for the ventilation equipment, i.e. a blower box or air-conditioning housing.

Shafts and chimneys

The museum has a number of structural shafts. These served originally to remove the flu gases from the fireplaces. Today a number of the shafts are used for removing the flu gas from the central heating boiler and the two gas stoves. A number of shafts are not in use and have been in partial disrepair.

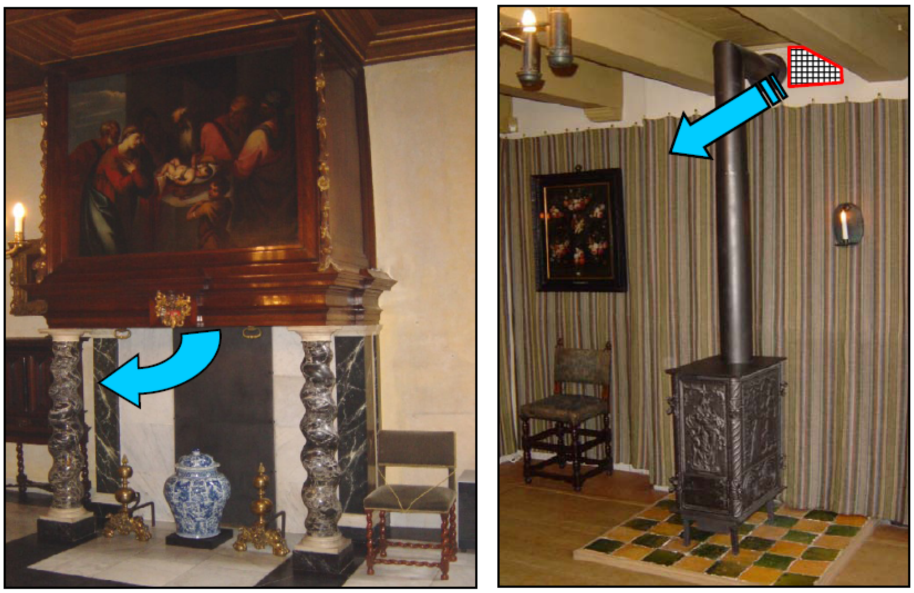


Figure 24 An example of a possibility for hiding the air inlet points in existing shafts and chimneys. The air can be brought into the Sael through a grate which is mounted flush with the chimney. It might be possible to ventilate the Canal room by utilizing a structural duct. A grate can be mounted flush with the duct which can then be connected to the shaft.

Shaft locations

See figures 3 through 6 for the diagrams showing the shaft locations. The locations are:
On the canal side of the building there is a structural flu gas duct. The flu gas ducts from the two gas stoves run to this duct.
In the past there was a structural flu gas duct which ran from the chimney in the Sael, via a double wall between the Silver Room and the chimney, to the building's south-west wall. This shaft is in partial disrepair.
There is a structural duct which runs from the chimney in the 19th century kitchen vertically towards the roof.
There is a structural duct on the top floor which runs to the roof. The flu gas removal duct of the central heating boiler is connected to this, as well as the chimney which is in the room next to the 17th century kitchen.

Possibilities of using the existing shafts

Given that most of these shafts go to a chimney in the roof, these ducts can be reached through the attics, where the shafts could be opened up for inserting ductwork. The disadvantage of such insertion into the structural shafts is that they could be difficult to reach for maintenance.

Opening at the location of the Lamp of God in the church

This opening in the floor can be used for blowing in or drawing off the church air. The diameter of the hole is approximately 55 cm. If we assume a free flow of 65%, the useful surface area would amount to 0.15 m².
If conditioned air were to be blown through this opening, care would have to be taken to prevent damaging the woodwork of the Lamp of God.

Table 7. Estimated potential ventilation rate through the opening at the Lamp of God.

Diameter	0.55 m
Free flow	65%
Useful surface area	0.154 m^2
Velocity over opening	2.5 m/s
Rate	1390 m^3/h

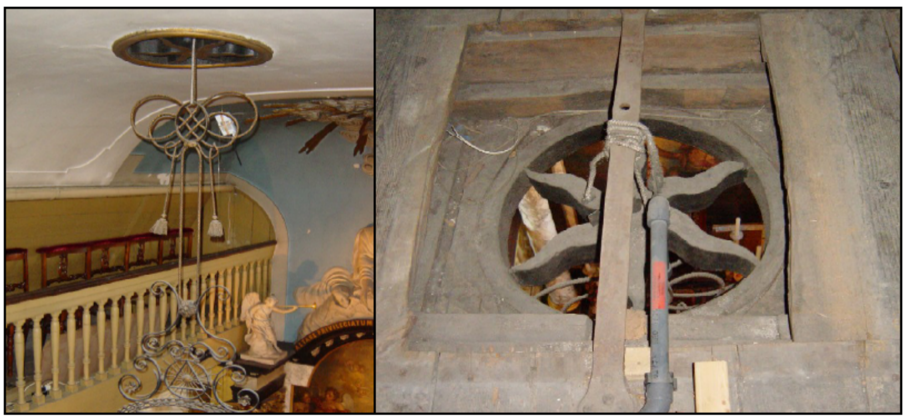


Figure 25 Where the Lamp of God is located, there is an opening in the church ceiling which could potentially serve for blowing in or drawing off air. The picture on the right shows this opening in the attic floor. The PVC pipe is part of the smoke detector system.

Ductwork

The ductwork should preferably be hidden where possible in order not to disturb the interior of the historic monument. Naturally it can also be mounted in sight, but that means concessions regarding the inside appearance.

Intake of outside air

Outside air can be drawn in via openings which can be made in the dormer windows in the attic.

Intake of ventilation air

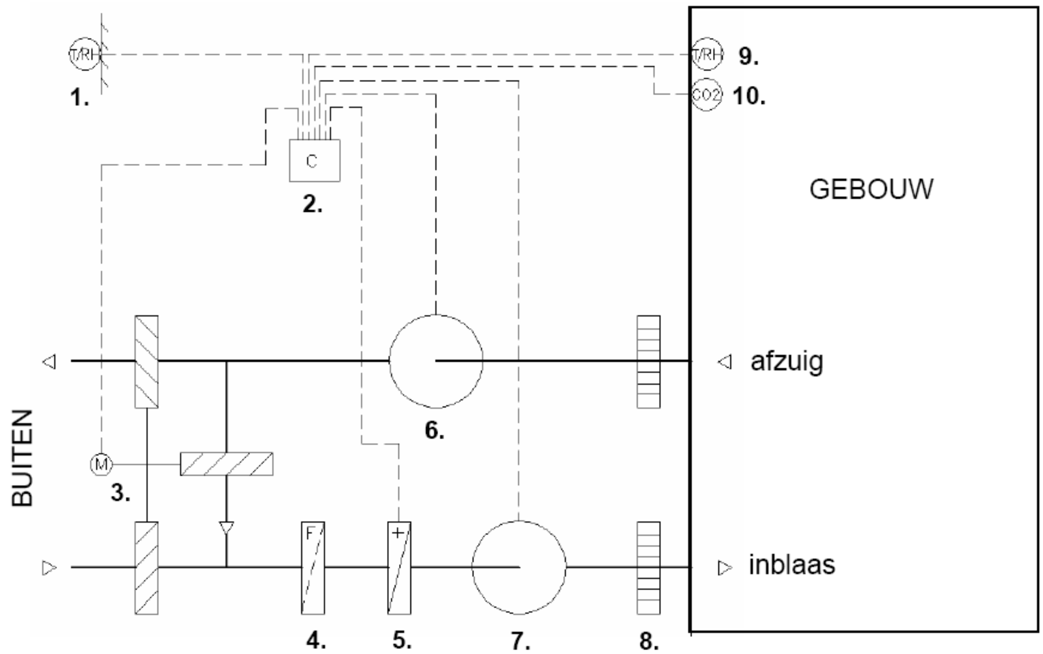
The following can be used as air intakes:

- existing chimneys
- openings made in the shafts and covered with a grate
- the opening in the church ceiling at the Lamp of God

Ventilation air exhaust

The existing chimneys or openings in the shafts covered with a grate can be used to exhaust air, as can the opening in the church ceiling at the Lamp of God.
Warning! Ductwork carrying cold air must be thermally isolated to prevent surface condensation on the duct.

10. Ventilation options



[Key:
Buiten = outside
Gebouw = building
afzuig = exhaust
inblaas = intake]

1. T/RH outside sensor
2. Regulator
3. Mixture valve section
4. Filter section
5. Air heater
6. Exhaust fan
7. Intake fan
8. Sound damper
9. Indoor T/RH sensor
10. Indoor CO_2 sensor

Figure 26 Circuit diagram of ventilating option 1. The basic concept is 100% recirculation. When the CO_2 or RH content of the indoor air exceeds the maximum permissible amounts, if possible, 100% recirculation will be switched over to mixing in the outside air.

Ventilation option 1: Combined intake and exhaust system

With this system, the air intake and exhaust are essentially brought into balance. Air is mechanically brought to a room via a duct system and mechanically removed from that room or to an adjacent room.
During normal operations, air expelled from the room is filtered and then blown back in on the basis of 100% recirculation. However, if for example during an event in the church the CO_2 content in the air rises above an adjustable limit, some outside air will be mixed in. See Figure 26. A condition for safely mixing in outside air is that the absolute moisture content of the outside air must be lower than the absolute moisture content of the air indoors. If the outside temperature is lower than indoors, the air that is drawn in is pre-warmed.
If the RH of the indoor air surpasses a maximum limit, for example 65%, the outside air can be mixed in to lower the RH. This is only possible if the absolute moisture content of the outside air is lower than indoors. Depending on the temperature outside, the air to be drawn in may have to be pre-heated.
It is important to prevent large fluctuations of the RH with this system. Outside air must only be mixed in when conditions absolutely make it necessary.

The CO_2 limit of 1200 ppm in the Church is most frequently exceeded when events are taking place, when large numbers of people present in the Church increase the production of moisture, causing the absolute moisture content of the indoor air to exceed that of the outside air. See Figure 27 for an example of the condition of the air during an event.

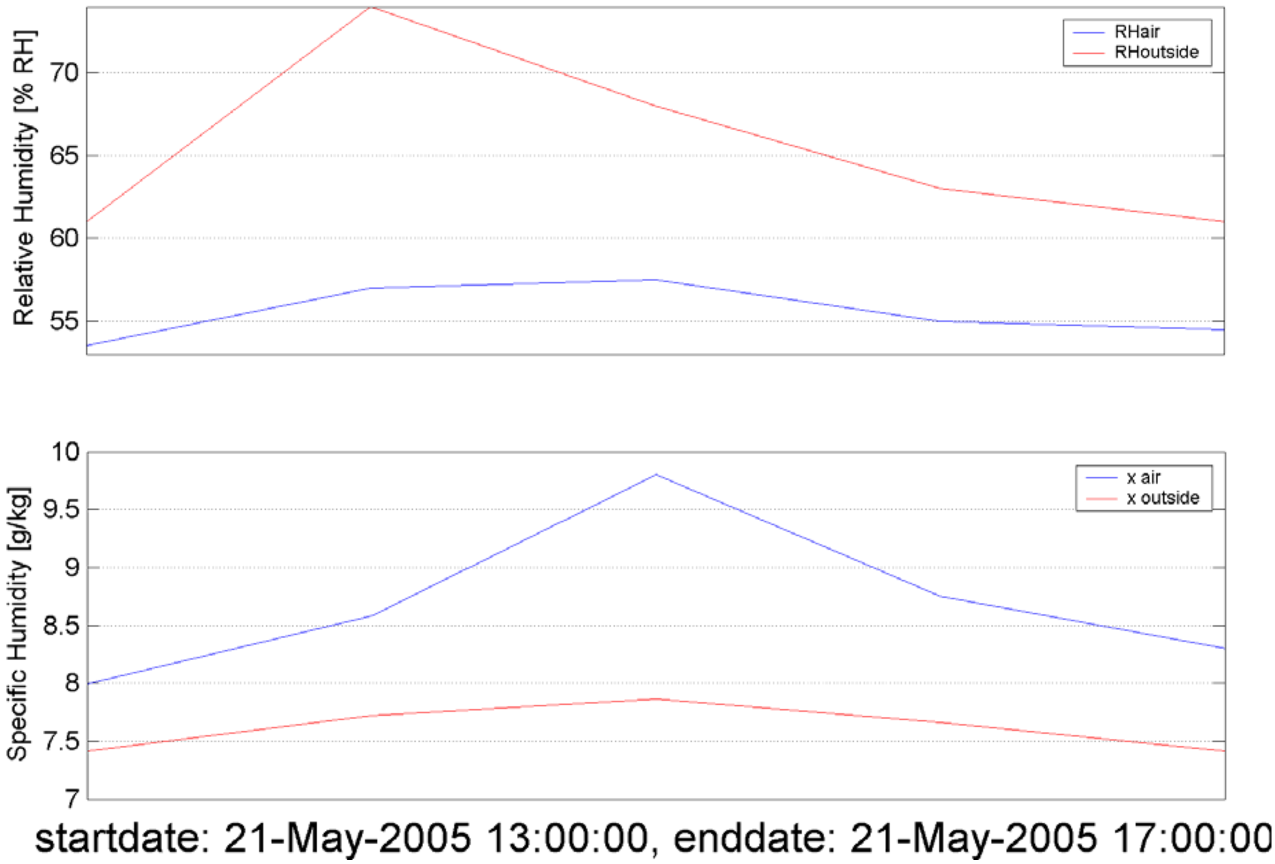


Figure 27 Record of the RH and the absolute moisture content of the indoor air measured in the church beneath the Lamp of God during an event. The graph also shows the condition of the outside air. On this day there was a wedding in the church between 2:30 pm and 3:30 pm attended by 110 people. When there is an event which has many visitors, the absolute moisture content of the indoor air will almost always be higher than the absolute moisture content outside.

When the indoor RH is too low (< 40%) during the heating season, it is not possible to mix in more humid outside air because the absolute moisture content of the indoor air in the building during the heating season (see Figure 28) is almost always higher than the absolute moisture content outside. Indoor RH levels that are too low primarily occur during the heating season. The RH can be increased during these periods by lowering the setpoint temperature by a few degrees.

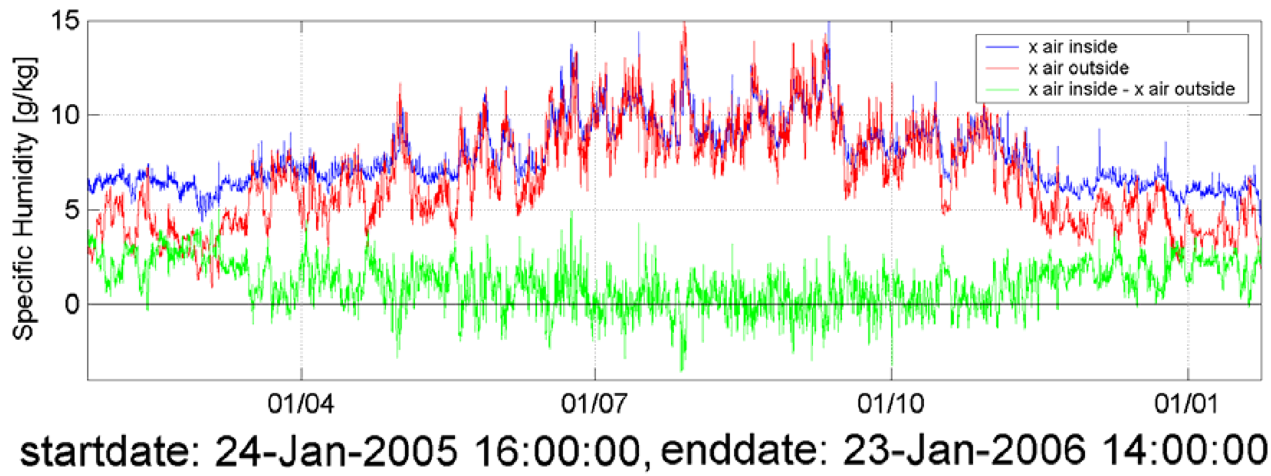


Figure 28 Record of the absolute moisture content of the indoor and outside air over a year. This graph also shows the difference between the two. During the heating season the absolute moisture content of the indoor air is usually higher than the absolute moisture content of the outside air.

Disadvantages: - ventilation using outside air depends upon outside weather conditions

Advantages:
- relatively simple system
- attractive from a installation standpoint
- intake air can be filtered
- intake air can be preheated

If the necessary ductwork can be hidden it is a good option for the targeted ventilation. For an example of such a system, see Figures 30 through Figure 33.

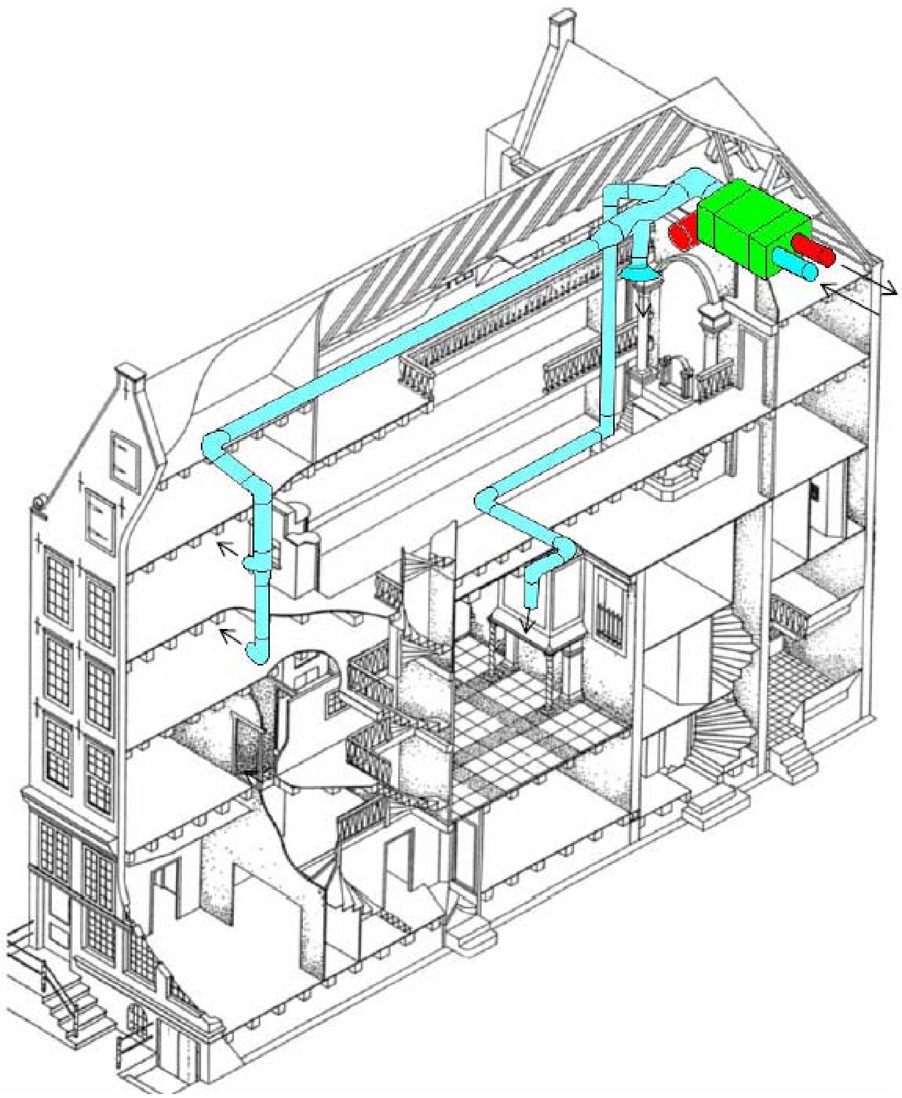
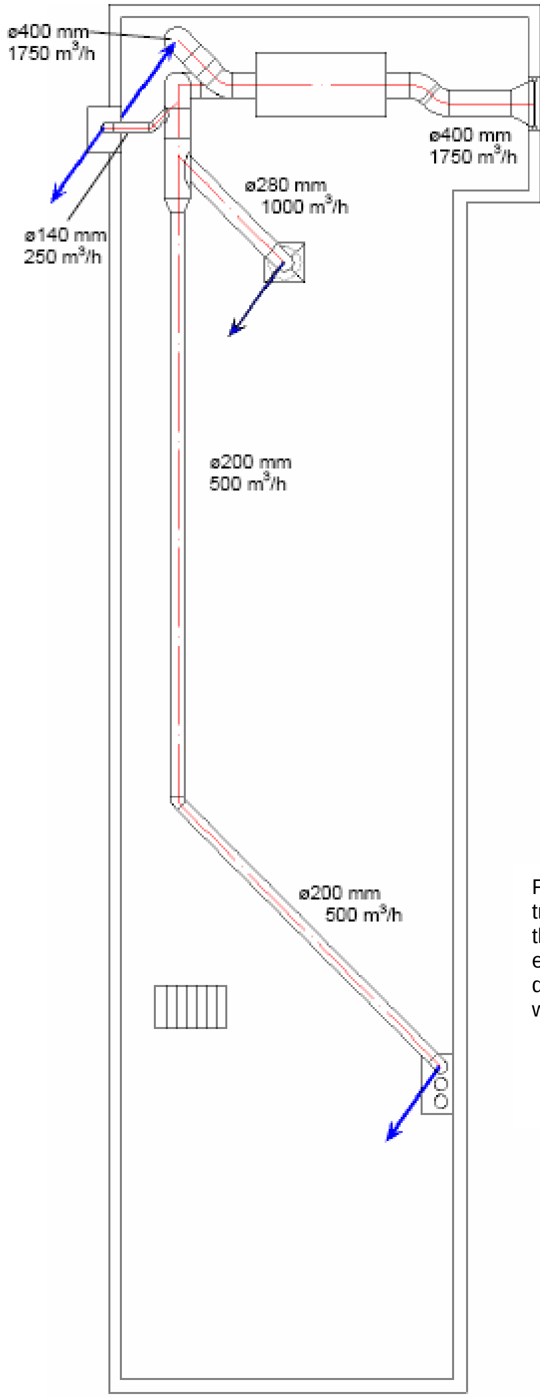


Figure 29 An example of a duct system in the building where there is both mechanical air intake and exhaust. Most of the ducts are not visible. Only in the Silver Room is the duct running along the ceiling visible. Air is drawn into the church in 3 locations, namely through the ceiling opening at the Lamp of God and through 2 openings on the canal side. The air is centrally expelled on the 2nd gallery. This air is filtered in the air-conditioning housing and may be mixed with the outside air and pre-heated, after which it is once again drawn in. In the Sael air is drawn in through the chimney. This air will flow to the staircase through an open door in the Sael.



Fi**gure 30** Drawing of a system with an air treatment housing and with the duct running in the attic. The ductwork is inserted into the 2 existing shafts in the attic. The air can be drawn in and expelled by modifying an existing window.

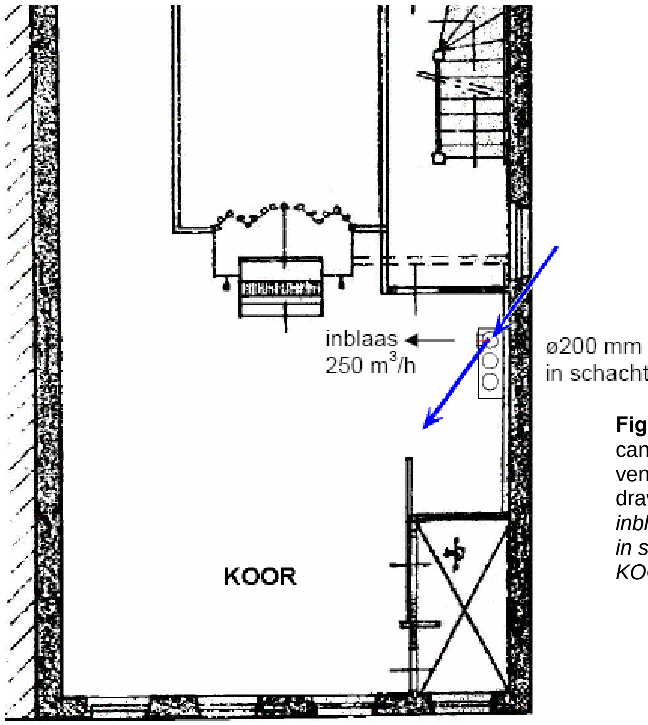


Figure 31 Detail of the space in the church on the 4th floor, canal side. Air is drawn into the church through the ventilation duct inserted in the shaft in the attic. The air is drawn in through a grate installed in the shaft. [Key:
inblaas = intake
in schacht = in the shaft
KOOR = choir]

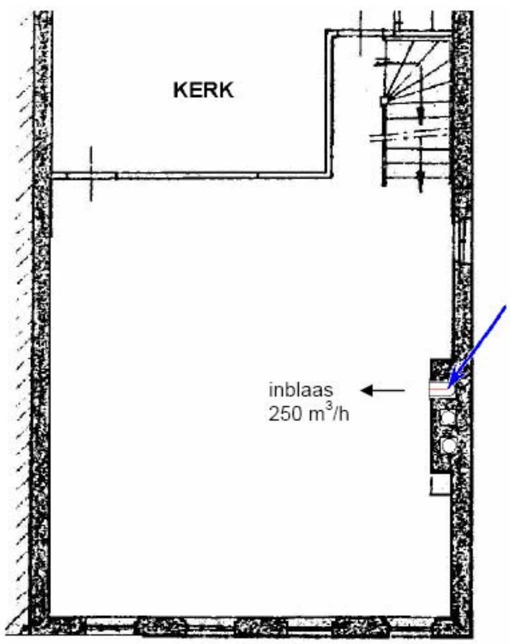


Figure 32 Detail of the space in the church on the 3rd floor, canal side. Air is drawn into the church through the ventilation duct inserted in the shaft in the attic. The air is drawn in through a grate installed in the shaft.
[Key:
KERK = church]

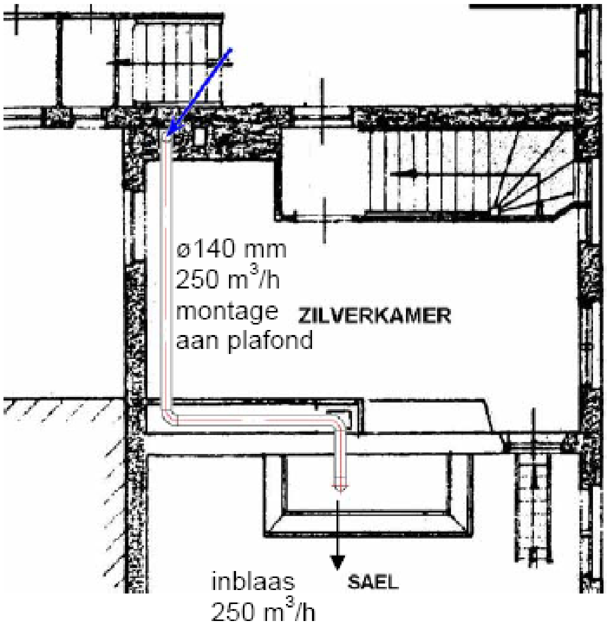


Figure 33 Detail of a duct that could be connected for ventilating the Sael. The ventilation duct installed in the attic, exits the shaft in the Silver Room and runs along the ceiling to the double wall between the Silver Room and the Sael. The ventilation duct then runs through the wall into the Sael chimney. By using a properly dimensioned grate for the intake, ventilation air is drawn into the Sael.
[Key:
inblaas = intake
montage aan plafond = ceiling mount
ZILVERKAMER = Silver Room
SAEL = Sael

11. Computer simulations

HAMBASE

Using the HAMBASE (Heat And Moisture Building And Systems Evaluation) [9] calculation program developed by TUE, it is possible to calculate the anticipated air and surface temperatures and relative humidity over the course of a year. When calculating with HAMBASE, the primary concern is the dynamic behavior of the indoor climate. Moreover, roughly speaking, it is possible to estimate the energy usage and the capacity required for heating, humidifying and dehumidifying. Climate data collected by the KNMI [*Koninklijk Nederlands Meteorologische Instituut* – Royal Dutch Meteorological Institute] was used for the calculation.
By using surface area temperature calculations, it can be determined if condensation might occur on the windows or the walls. Surface temperature information is also required for making calculations using the Fluent CFD-program.

Simulation settings in HAMBASE

The Sael is the space for which the calculations were performed. The physical material used for the calculations were those which had been gathered on-site. When this information was insufficient, the TUE data base was used. Table 8 gives an overview of the variants calculated by HAMBASE for the Sael. This regards the following simulation variants:

1. Variant 1: current situation with the humidifiers and dehumidifiers in place, no ventilation
2. Variant 2: situation without portable humidifiers and dehumidifiers, no ventilation
3. Variant 3: situation without portable humidifiers and dehumidifiers, with ventilation
4. Variant 4: situation without portable humidifiers and dehumidifiers, with ventilation and dehumidifying the intake air

Table 8 Overview of the HAMBASE calculation* variants for the Sael

Variant	Portable humidifier	Portable dehumidifier	Ventilation	Dehumidifying intake air
1	X	X	-	-
2	-	-	-	-
3	-	-	X	-
4	-	-	X	X

* The KNMI outside climate data for the year 2005 was used for the calculations

Table 9 Starting points HAMBASE simulation for the Sael

Variant	Day/night T[1] [ºC]	Heating capacity [W]	Internal heating load[2] [W]	Internal moisture content[3] [kg/s]	Humidifying-dehumidifying cap. [kg/s]	W [h^{-1}]
1	20/18	3000	750	0.00005	0.00005/0.00004	0.2
2	20/18	3000	750	0.00005	none	0.2
3	20/18	3000	750	0.00005	none	1.2
4	20/18	3000	750	0.00005	0.0/0.0003	1.2

1. The intake temperatures cannot be used in the simulation, only the thermostat values.
2. Due to people and lighting, between 10 am and 5 pm.
3. Due to people, between 10 am and 5 pm.

HAMBASE Results

The results of the HAMBASE calculations are given in the graph in Appendix D. HAMBASE primarily takes into consideration the progress over time of the temperature and relative humidity in the Sael. The surface conditions which occur are another important aspect.

<u>Variant 1</u>:
Air temperature and relative humidity
See Figure 59 in Appendix D. In the summertime, the temperature can exceed 25º C. The RH is fairly constant due to the humidifiers and dehumidifiers.
Surface conditions
See Figure 60 in Appendix D. There is no condensation on the glass when the weather is cold outside. The RH near the surface of the wall regularly exceeds 70% which increases the danger of mold growth.

<u>Variant 2</u>:
Air temperature and relative humidity
See Figure 61 in Appendix D. As a result of the operation of the heating system, the RH's in the winter are lower than desired. During the other seasons, the RH is higher than desired, which requires dehumidifying. The RH can be increased during the heating season by lowering the setpoint temperature.
Surface conditions
See Figure 62 in Appendix D. Because there is no dehumidifying, there will be heavy condensation on the glass. Most of the time the RH at the wall surface exceeds 70%, which increases the danger of mold growth.

<u>Variant 3</u>:
Air temperature and relative humidity
See Figure 63 in Appendix D. By using the outside air for ventilation, the relative humidity reaches unacceptably high values.
Surface conditions
See Figure 64 in Appendix D. As a result of using outside air for ventilation, condensation forms on the glass and also potentially on the cold walls.

<u>Variant 4</u>:
Air temperature and relative humidity
See Figure 65 in Appendix D. By dehumidifying the intake air, the RH remains under 60% for the entire year monitored. During the heating season, the RH values are too low.
Surface conditions
See Figure 66 in Appendix D. There is hardly any condensation on the glass. The RH near the wall surface regularly exceeds 70%, which increases the danger of mold growth.

Fluent

The CFD-calculations (Computational Fluid Dynamics) using the Fluent [10] program can show the expected air flow and temperature distribution in the Church and the Sael. Attention was also paid to the anticipated vertical stratification of the temperature in the Church and the anticipated air distribution in the Church and the Sael resulting from the ventilation system. No relative humidity calculations were made using Fluent. However, it is possible to say something about the distribution of the relative humidity based on the temperature distribution.
Among other things, the work done included the use of 3D geometry for a simplified model of the Church and the Sael in the CFD program, and calculations of different variants for the heating system and the different seasons. See the figure below for the geometry of the Sael.

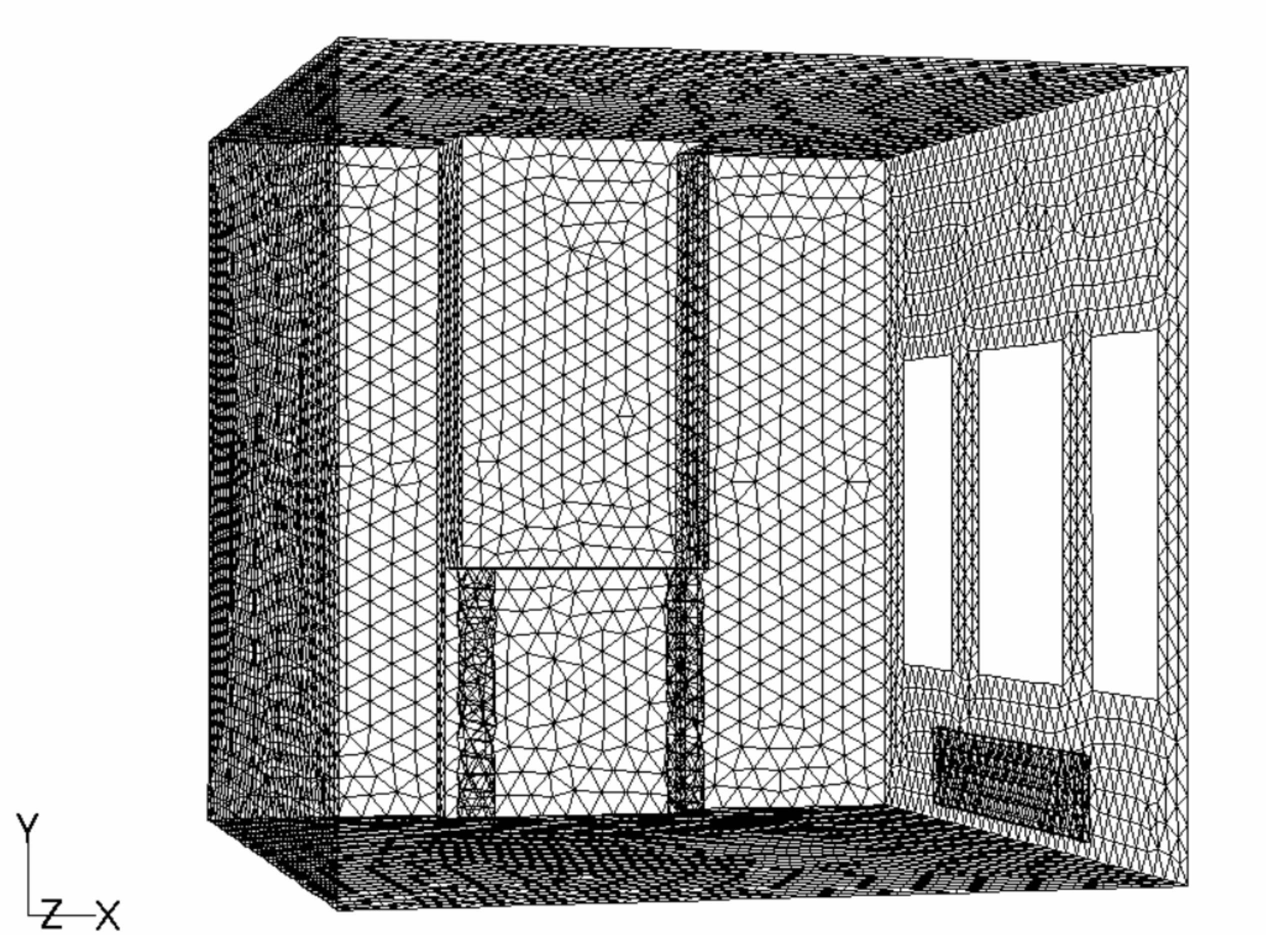


Figure 34. A presentation of the geometry of the Sael, as used in the Fluent model.

Simulation settings in Fluent

These calculations give a three-dimensional image of the progression of air velocity and air temperature in the room. The room's boundary conditions were taken as constant for the purposes of the calculation, i.e., the surface temperatures do not change while the calculations are being made. The air intake conditions, both velocity and temperature are considered to be constant.
There were more variant calculations done than are contained in this report. The reason for this is that first, this is supposed to be a summary report; second, the process of simulation is one of searching for convergent solutions. A chronologically complete report of all the variants often does not benefit clarity.

Calculations were made for different variants, where the following conditions were varied:

- season (summer/winter)
- heating (on/off)
- ventilation (on/off, amount of air, air temperature)
- location of the grates

Sael simulation setting

The following variants were calculated for the Sael:

- Variant 1: the Sael in the current situation in the summer
- Variant 2: the Sael in the current situation in the winter
- Variant 3: the Sael provided with mechanical ventilation, summer conditions
- Variant 4: the Sael provided with mechanical ventilation, winter conditions

The entrance door of the Sael was assumed to be open. It was also assumed that the quantity of air flowing into the Sael through the grate, was the same as that which flows out of the open door to the hallway. For an overview of the calculated variants for the Sael, see Table 10. For an overview of the grate variants used, see Table 11.

The surface temperature of the glass and the outside wall which are given in Table 10 are estimates calculated by the HAMBASE. These are the minimum temperatures that occur when the calculation is done for the period of one year. The surface temperatures for the inside walls, floor and ceiling, were set at 20ºC.

Church simulation setting

For the Church, the following variants were calculated:

- Variant 1: the Church in the current situation in the summer
- Variant 2: the Church provided with mechanical ventilation, grate variant 1, summer situation

Table 10 gives an overview of the variants which were calculated with Fluent. In Table 11, the grate variant used is further elaborated.

Table 10 Overview of the variants calculated using CFD

	Variant	Season*	Type of ventilation	Heating	Grate variant
Sael	1	Summer	None	Off	n.a.
	2	Winter	None	On	n.a.
	3	Summer	intake	Off	1
	4	Winter (11/6)	intake with preheating of air	On	1
Church	1	Winter	None	On	n.a.
	2	Winter	Intake	On	1

* Parenthetically, the outside wall temperature/glass temperature reported is the one used during the simulation. This value was derived by the HAMBASE calculations.

Table 11 Data from the grate variants used

	Grate variant	Type of grate	Grate surface	Intake temperature	Intake velocity [m/s]	Rate of flow [m3/h]
Sael	1	1x intake Ø0.30 m	0.061	22	1.05	250
Church	1	1x intake above the Lamp of God	0.280	22	1	1000
		2x intake 0.06 canal side	25	22	1.2	500

Sael results

The results of the CFD calculations for the Sael are given on the graph in Appendix F. These results have not been validated and are therefore only to be used as indications.

Variant 1:
See Figure 68.
- **Temperature distribution**

A very slight vertical temperature stratification was measured.
- **Air velocities**

The air velocities in the Sael were very low.

Variant 2:
See Figure 69.
- **Temperature distribution**

Good temperature distribution.

- **Air velocities**

Airflow results in the Sael due to the flow of heat from the radiator.

Variant 3:
See figure 70.

- **Temperature distribution**

The distribution of air temperature can be said to be reasonably uniform.

- **Air velocities**

When bringing in a quantity of air of 250 m^3/h at 1.05 m/s, there is no perceptible draft in the living area.

Variant 4:

See Figure 71.

- **Temperature distribution**

The distribution of the temperature is uniform.

- **Air velocities**

Airflow results in the Sael due to the flow of heat from the radiator. When bringing in a quantity of air of 250 m^3/h at 1.05 m/s, there is no perceptible draft in the area.

Church results

The results of the CFD calculations for the Church are given in the graph in Appendix G. These results have not been validated.

Variant 1:

- **Temperature distribution**

See Figure 72. A slight vertical thermal stratification of some few degrees is perceptible in the Church. As a result of the installed radiators, the air temperature distribution in the Church is not homogeneous.

- **Air velocities**

See Figure 73. Airflow results in the Church due to the flow of heat from the radiator.

Variant 2:

- **Temperature distribution**

See Figure 74.

- **Air velocities**

See Figure 75. When bringing in a quantity of air of 1000m^3/h at 1 m/s through the Lamp of God, and twice 250 m^3/h via the shaft on the canal side at 1.2 m/s, there is no measurable draft in the indoor environment. The velocity of the air in the indoor environment is approximately 0.15 m/s.

Conclusions and recommendations

Indoor climate

From the standpoint of a museum the air inside the Church can be said to be frankly good for this class of building, except for the excess temperatures in the summer. This is also true for objects not placed adjacent to the cold outside walls and which are not located in the direct vicinity of humidifiers, dehumidifiers and heating elements.
However, in the Sael and the Canal room the indoor climate in the winter is too dry because of the heating system. By setting the temperature in these rooms a few degrees lower, for example to 17 or 18 ºC instead of the current 20ºC, the RH-content during the heating season can be improved without losing comfort.
Particularly in the Antechamber, there are huge RH fluctuations per 24 hours. This is a consequence of outside air entering through the Antechamber door.

What is of concern to the museum, on the other hand, is moist air on cold surfaces such as glass, particularly on the north wall. During cold periods there is regularly condensation resulting from the high specific moisture content of the air indoors. This may explain the damage to the beam heads, for example.
Art objects are often placed against the outside wall, which results in very high RH's near and behind the object during cold periods, and sometimes in condensation. This situation can be improved by lowering the temperature as mentioned above and by lowering the humidifier settings to, for example, 40 to 45%.

Location of humidifiers and dehumidifiers

Recommendations for the portable humidifiers and dehumidifiers:

- preferably do not put them in front of radiators: because of the relatively warm and dry air around the radiator, the built-in hygrostat will not measure representative values
- preferably do not place in the direct vicinity of art objects: the exhaust from these apparatus can differ from the pre-set RH
- preferably humidifiers and dehumidifiers should not be placed near each other
- if humidifiers and dehumidifiers are placed in the same room, their setpoints must be significantly different, e.g., the dehumidifier should be set 10% higher.
- the use of the humidifiers should be reduced by 40 to 45% during the winter.

Window Condensation

There is a lot of condensation on the inside of the museum's windows during cold periods. This is undesirable because it may damage the woodwork around the glass (rotting/mold). The following steps can be taken to reduce/prevent this condensation:

- place the portable humidifiers/dehumidifiers in the right locations
- lower the setpoint of the portable humidifiers to, for example, 40 to 45% in the winter
- install double pane windows or a storm window which allows for ventilation.

Direct sunlight

At a number of locations in the museum, such as the altar, there are objects which at certain times of the year are subject to direct sunlight. This can lead to an increase of the rate of decay of the objects. It is important to treat the relevant glass with something to protect against the sun.

The intensity of the light near the altar is too high from the standpoint of the preservation of the collection. The cause of this is direct sunlight; the sun's infrared rays will increase the surface temperature. Sun shading or a UV-filtering membrane which also screens out a part of the infrared and visible light components can offer a solution here. Given that there is a painting on the altar, it is recommended that the lighting intensity not exceed 150 Lux [3].

Ventilation

Installing a ventilation system to control and balance moisture should be considered to deal with the undesirable conditions which occur when the traffic in the building is high. In the current situation, the rooms may not have sufficient fresh air.
Concealing the ventilation system ductwork to be installed presents a problem. One possible solution would be to use, where possible, the space available in existing chimneys, shafts and other openings in the structure.

Heating system recommendations

It will be possible to partially compensate for the low RH's of the indoor air during the heating season by lowering the heating system's current temperature setpoint by a few degrees.
Installing a simple ventilation system with an intake point in the Sael and intake and exhaust in the Church can offer a solution. During normal operations the indoor air is recirculated and filtered. The system is determined by the concentration of CO_2 in the Church and the absolute moisture content of the indoor and outside air. When the concentration of CO_2 is high (>1200 ppm), the outside air can be mixed in, with potential preheating during cold periods. In general, the maintenance of the ventilation system is limited to annual sensor calibration and filter replacement.
By installing air treatment equipment such as mentioned above and lowering of the temperature setpoint the portable humidifiers need no longer be used.

Simulations

Simulations in HAMBASE show that when outside is air is used for ventilation, there is a danger of surface condensation in the building. A solution to this is to ventilate with de-humidified outside air, or to only ventilate with outside air if the absolute moisture content outside is lower than indoors.
Using CFD-calculations it was shown that there is a minimum vertical thermal stratification in the church, which was validated by the measurements below the Lamp of God.
There is insufficient measurement data available to validate the other CFD results.

Follow-up investigations

- Possible expansion of the Fluent model to include CO_2, validation by means of air current measurements.
- Processing the measurement data with the CO_2 measurements.

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10. Fluent Inc., *Fluent User 's Guide*, version 6.1, Lebanon USA, 2003

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APPENDIX A: Data Sheet Siemens RVL 46

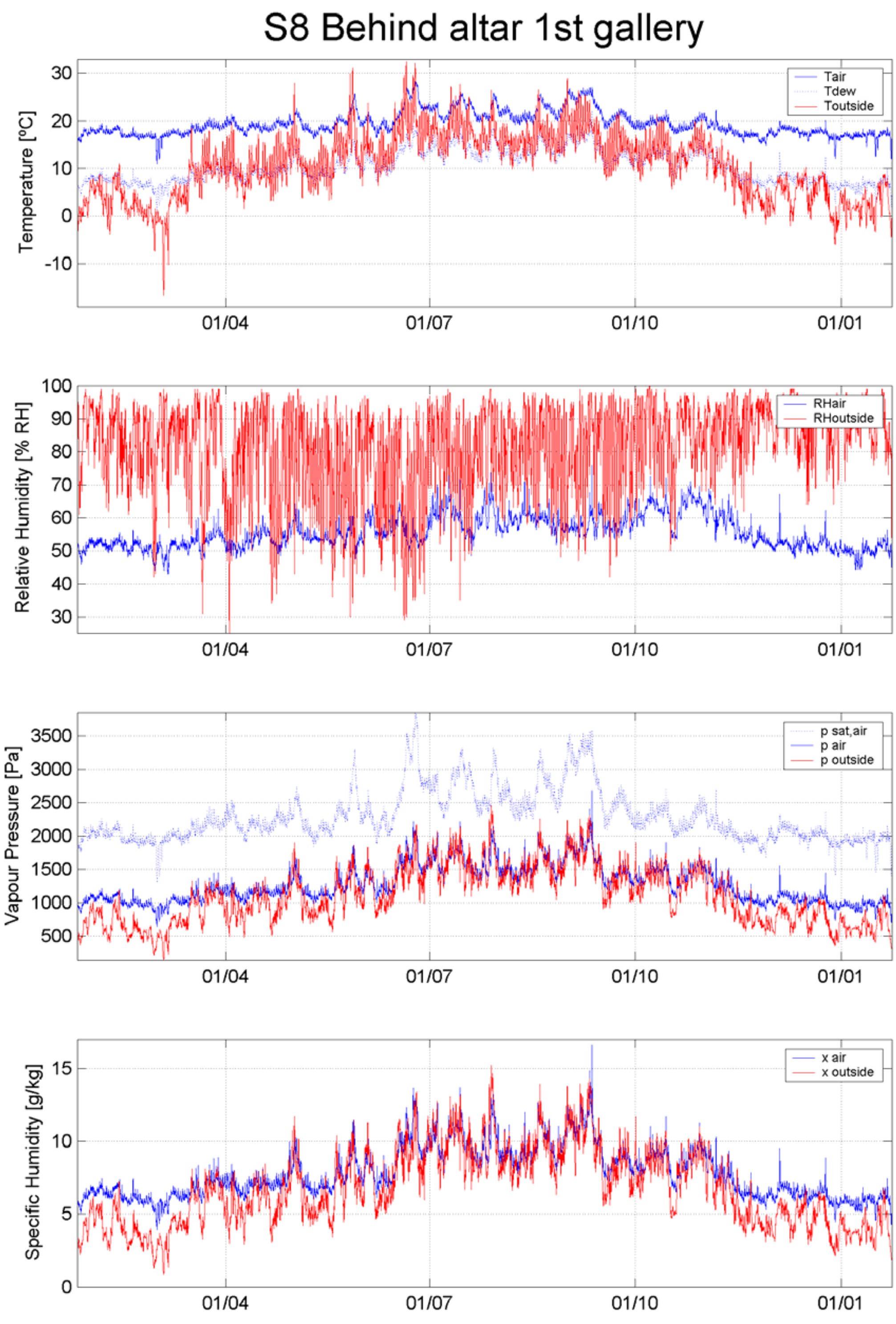
Appendix B: Indoor climate analytical graphs

The following pages give the analytical graphs for the following locations in the rooms where ICN performed measurements:

- Behind the altar 1st gallery
- Church, below the Lamp of God, low
- Church, below the Lamp of God, middle
- Church, below the Lamp of God, high
- Church, near the organ
- Sael
- Canal Room
- Antechamber above the reception desk
- Beam head in the vestry cupboard
- Church wall surface, north side
- Church window sill surface, north side
- Church window sill, north side
- Outside

These graphs clearly show the progression of the relative humidity and temperature. A number of statistical values are also given. The last graph shows the values on a Mollier diagram for each measuring location. The graph also gives the desired climate range as per the climate requirements of ASHRAE class B.

Behind the altar, 1st gallery



Starting date: Jan-24-2005 4:00 pm; end date: Jan-23-2006 2:00 pm

Figure 35 In the graphs above, the measured T and RH are plotted versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

S8 Behind the altar, 1st gallery

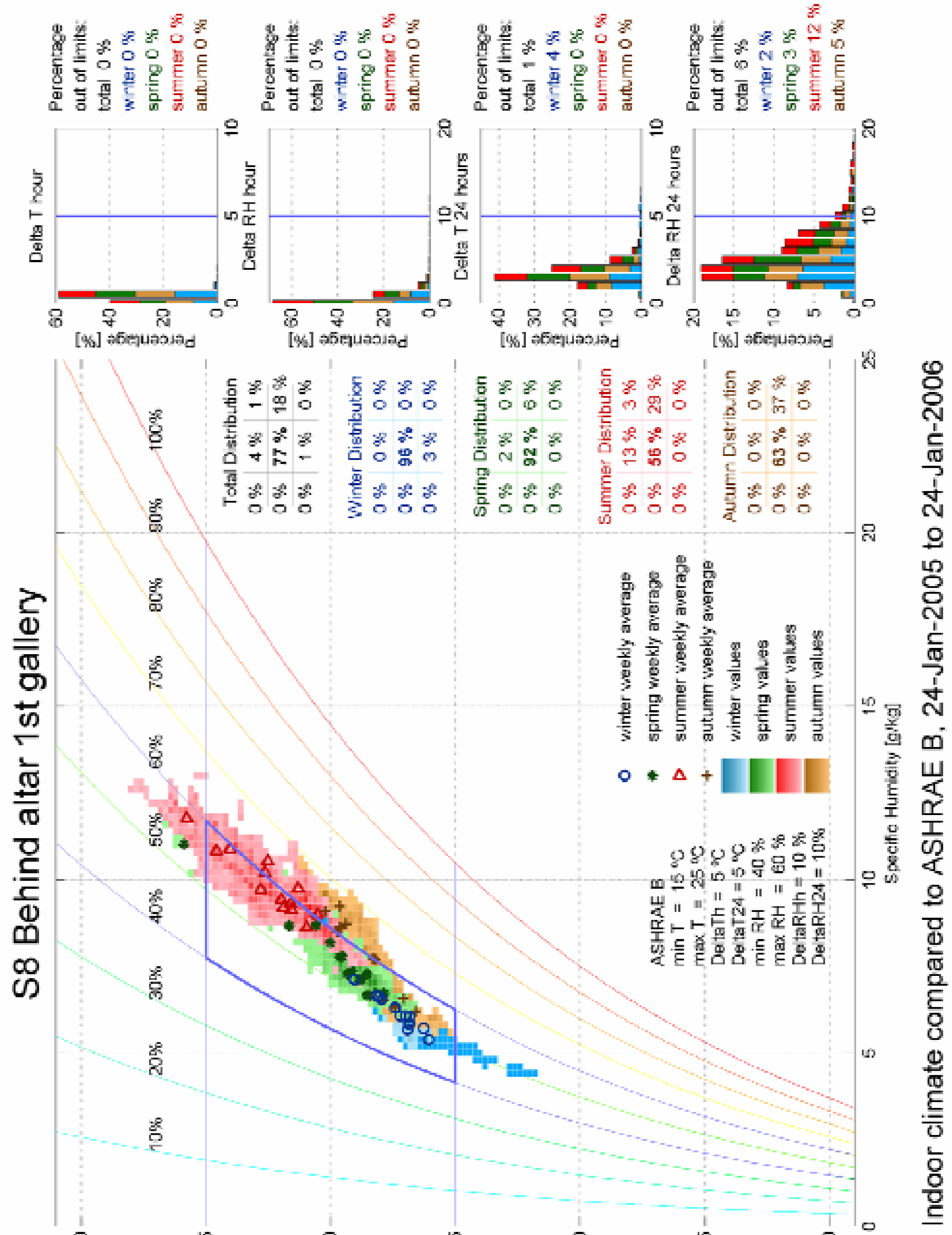
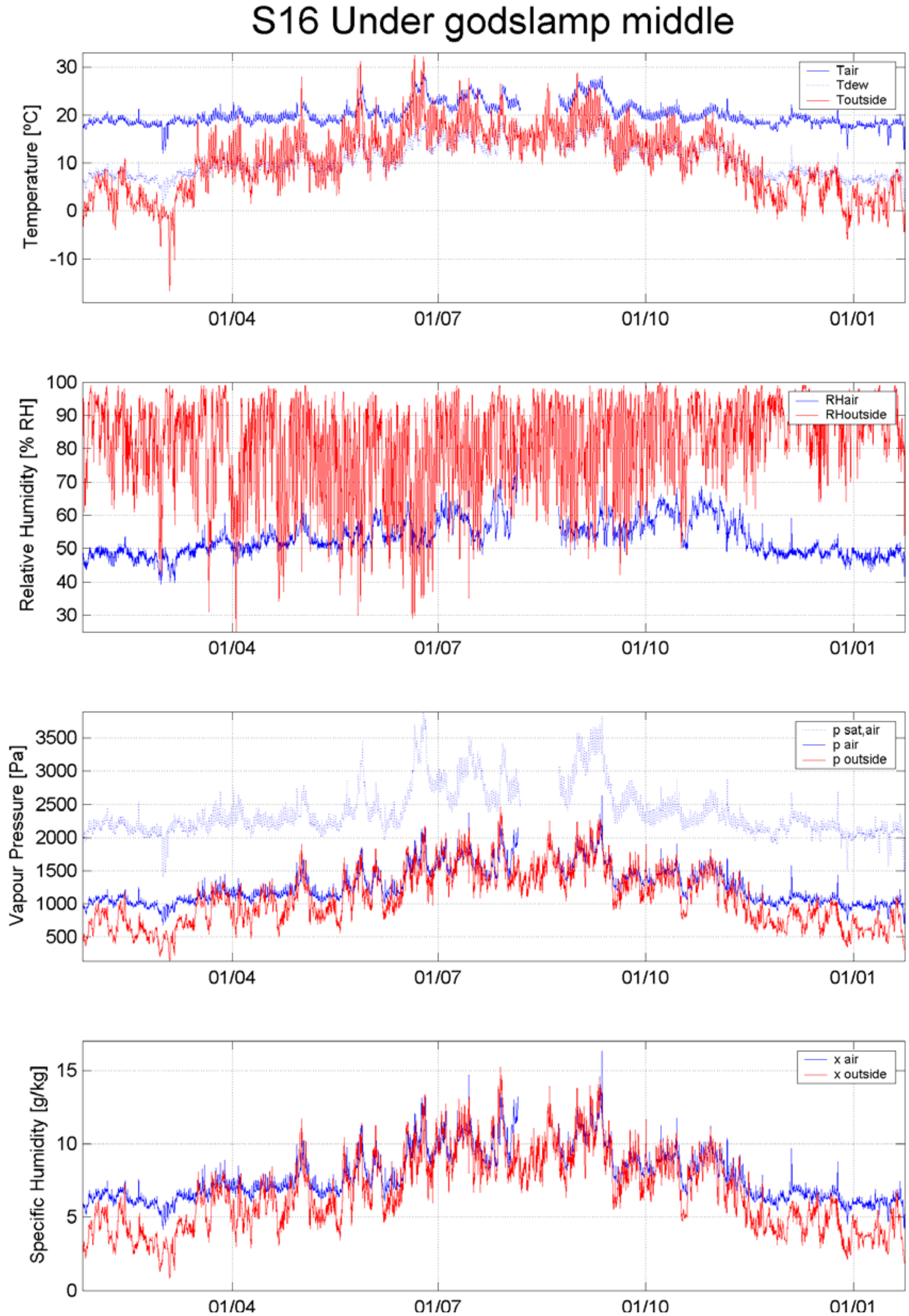


Figure 36 The measured values as recorded on the Mollier diagram, with a record of the hourly and daily fluctuations in T and RH on the right.

Church below the Lamp of God, middle



Starting date: Jan-24-2005 4:00 pm; end date: Jan-23-2006 2:00 pm

Figure 37 In the graphs above, the measured T and RH are plotted versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

S16 Below the Lamp of God, middle

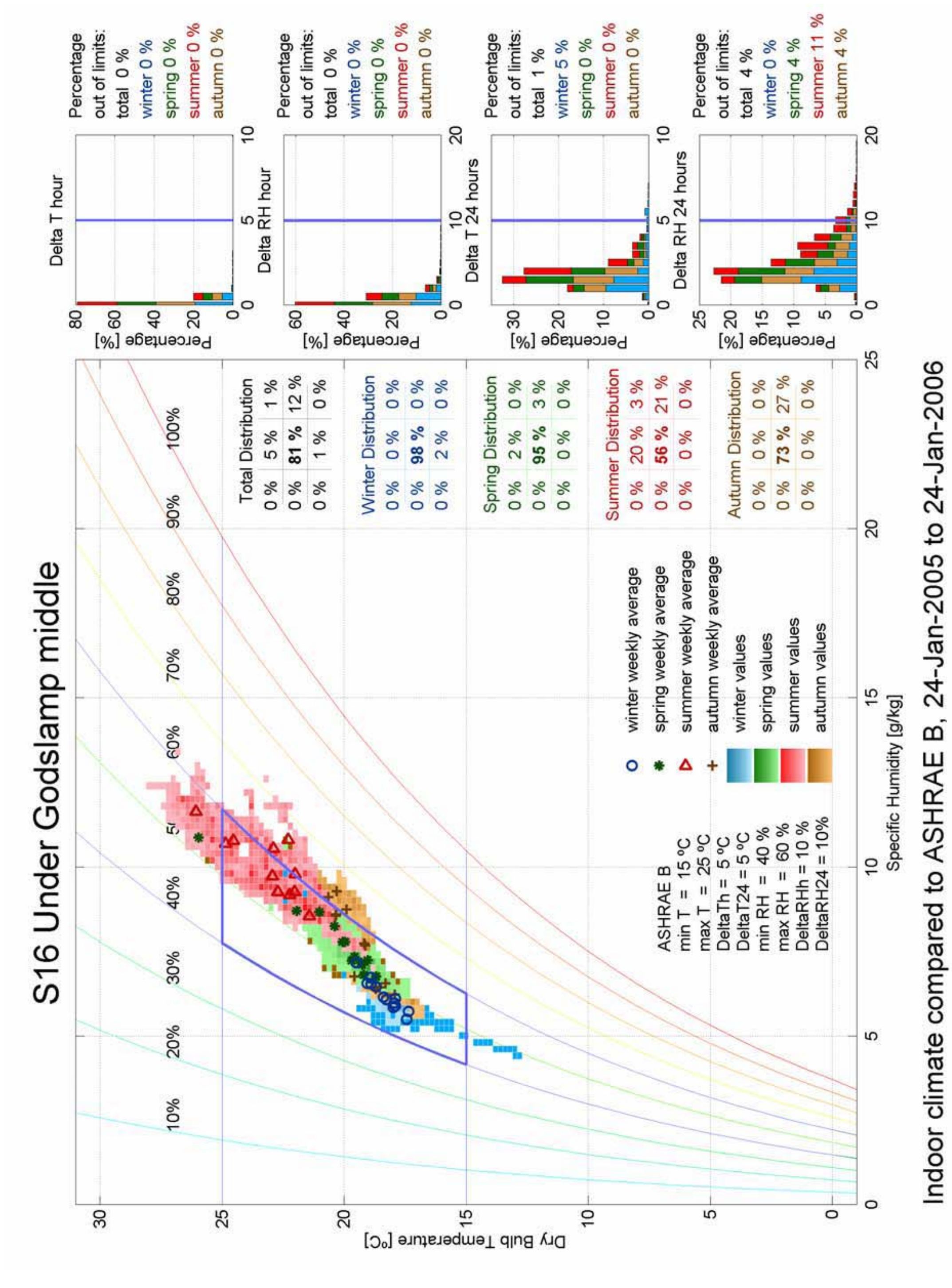


Figure 38 The measured values as recorded on the Mollier diagram, with a record of the hourly and daily fluctuations in T and RH on the right.

Church, near the organ

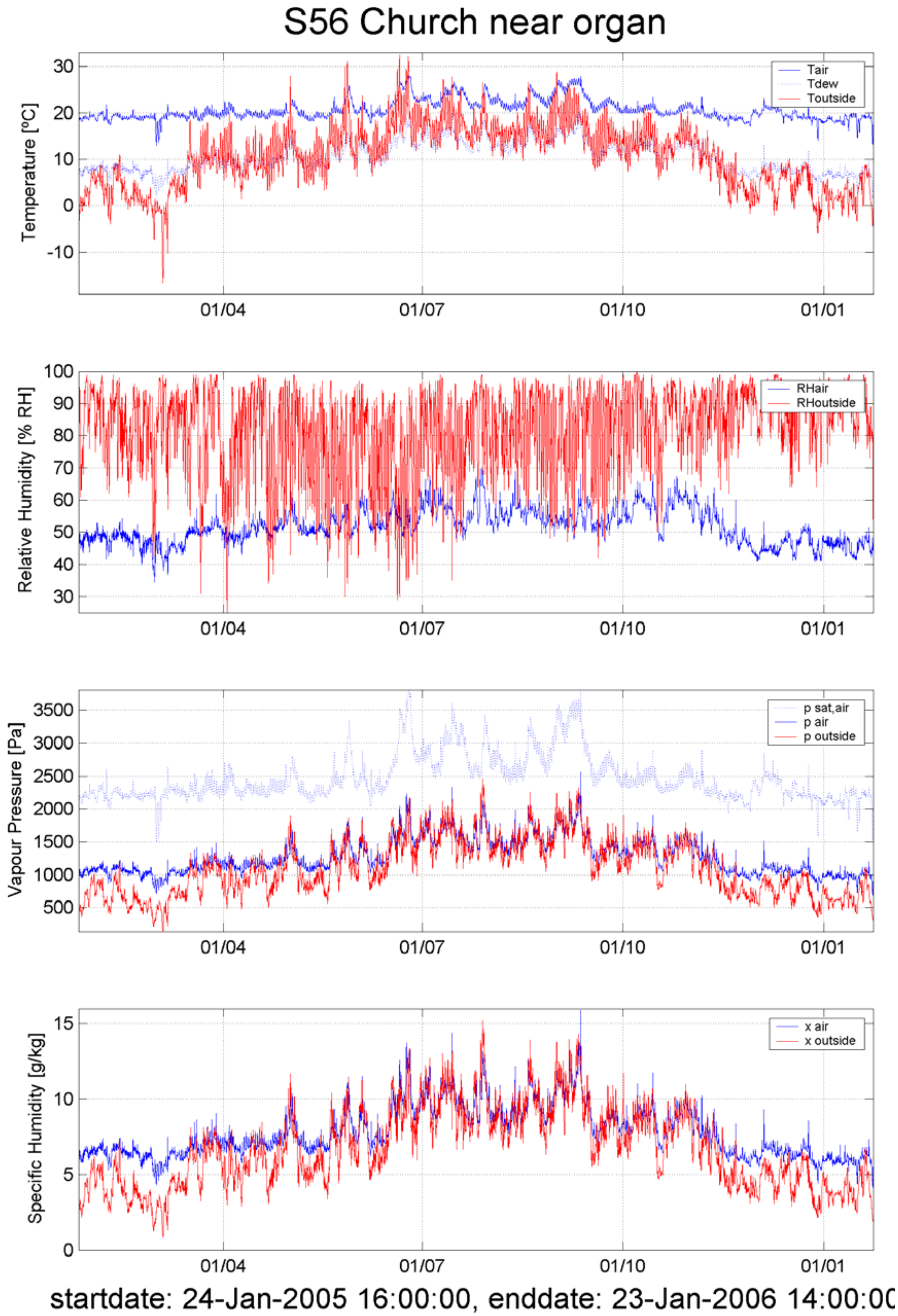


Figure 39 In the graphs above, the measured T and RH are plotted versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

S56 Church, near the organ

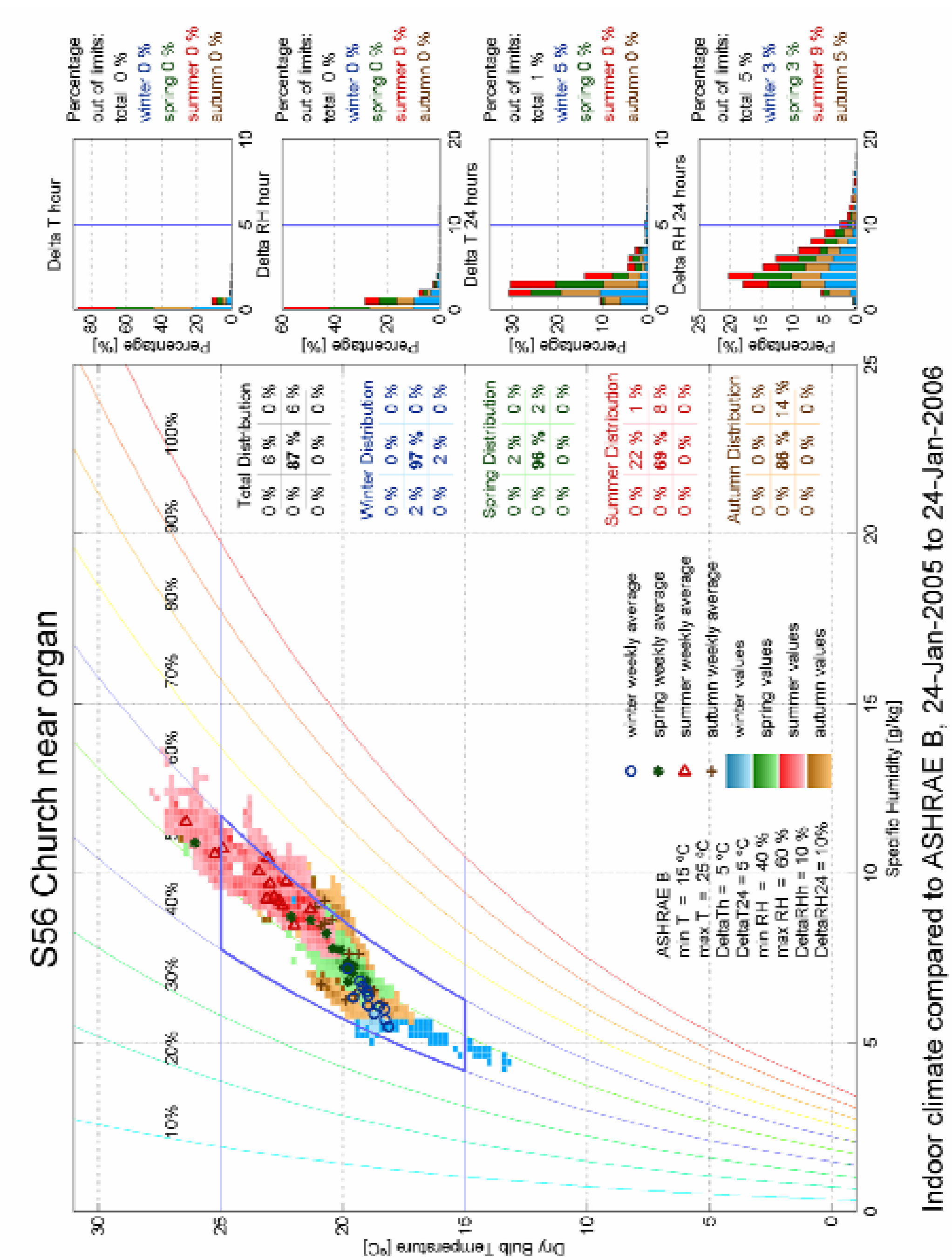


Figure 40 The measured values as recorded on the Mollier diagram, with a record of the hourly and daily fluctuations in T and RH on the right.

Sael

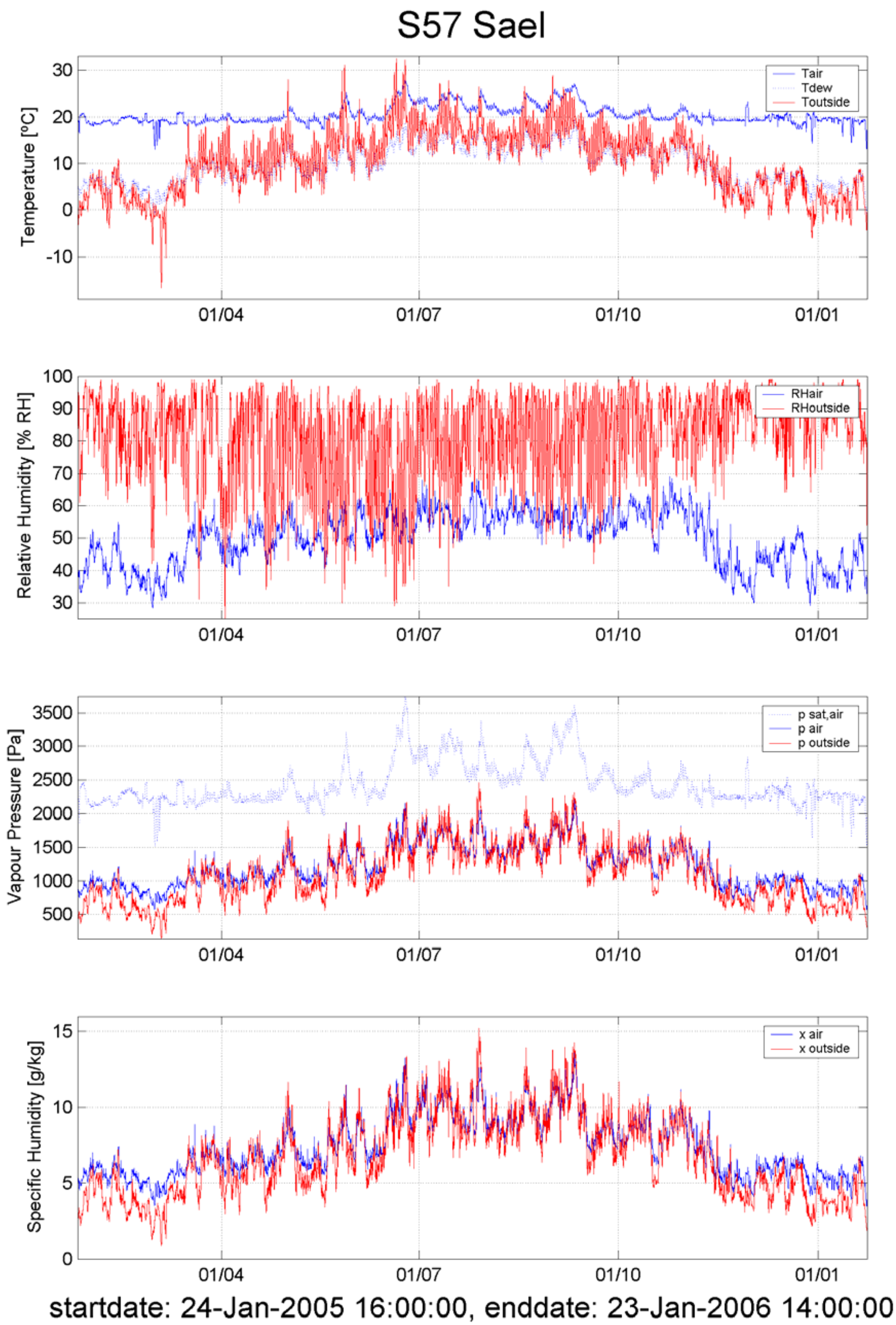


Figure 41 In the graphs above, the measured T and RH are plotted versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

S57 Sael

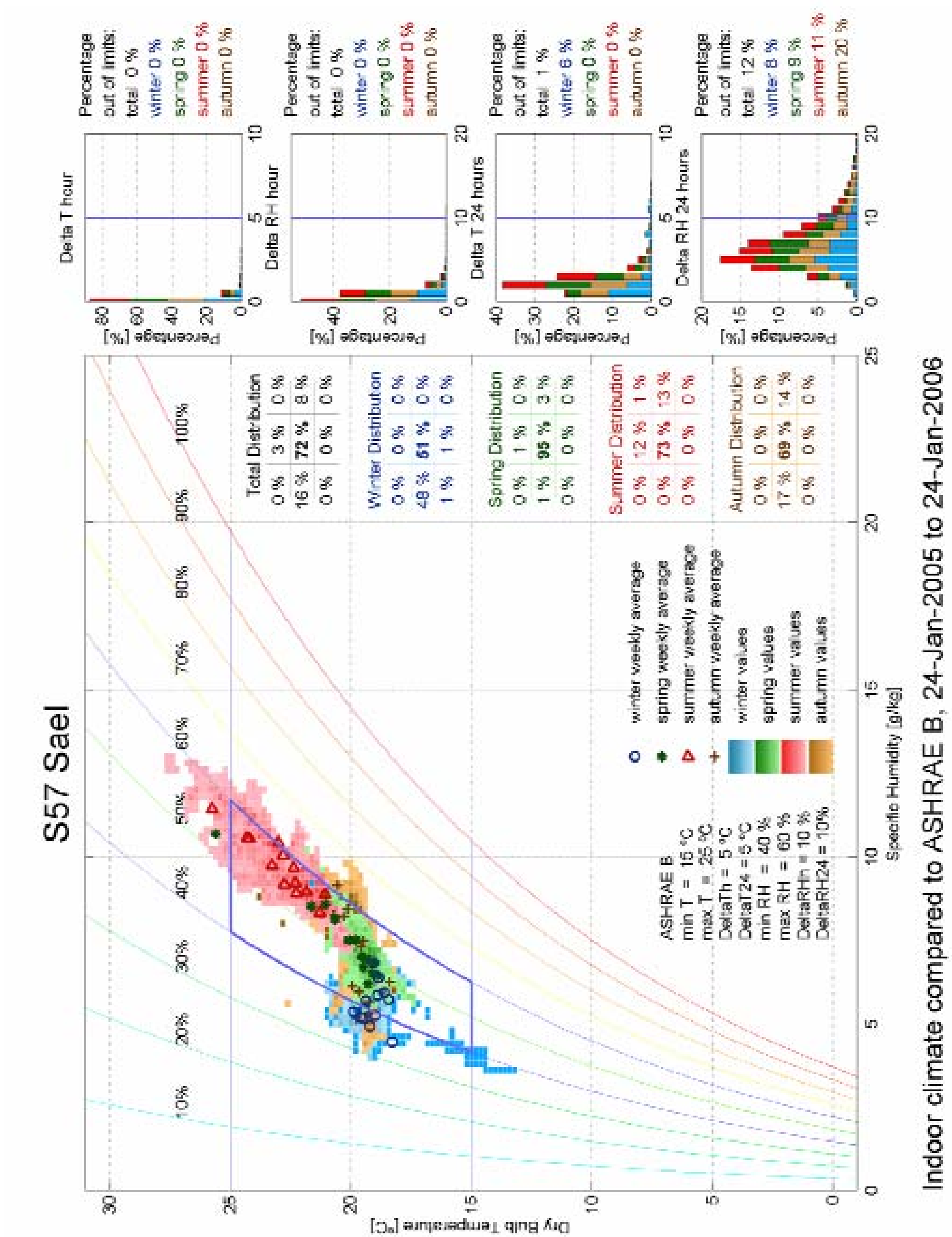


Figure 42 The measured values as recorded on the Mollier diagram, with a record of the hourly and daily fluctuations in T and RH on the right.

Canal Room

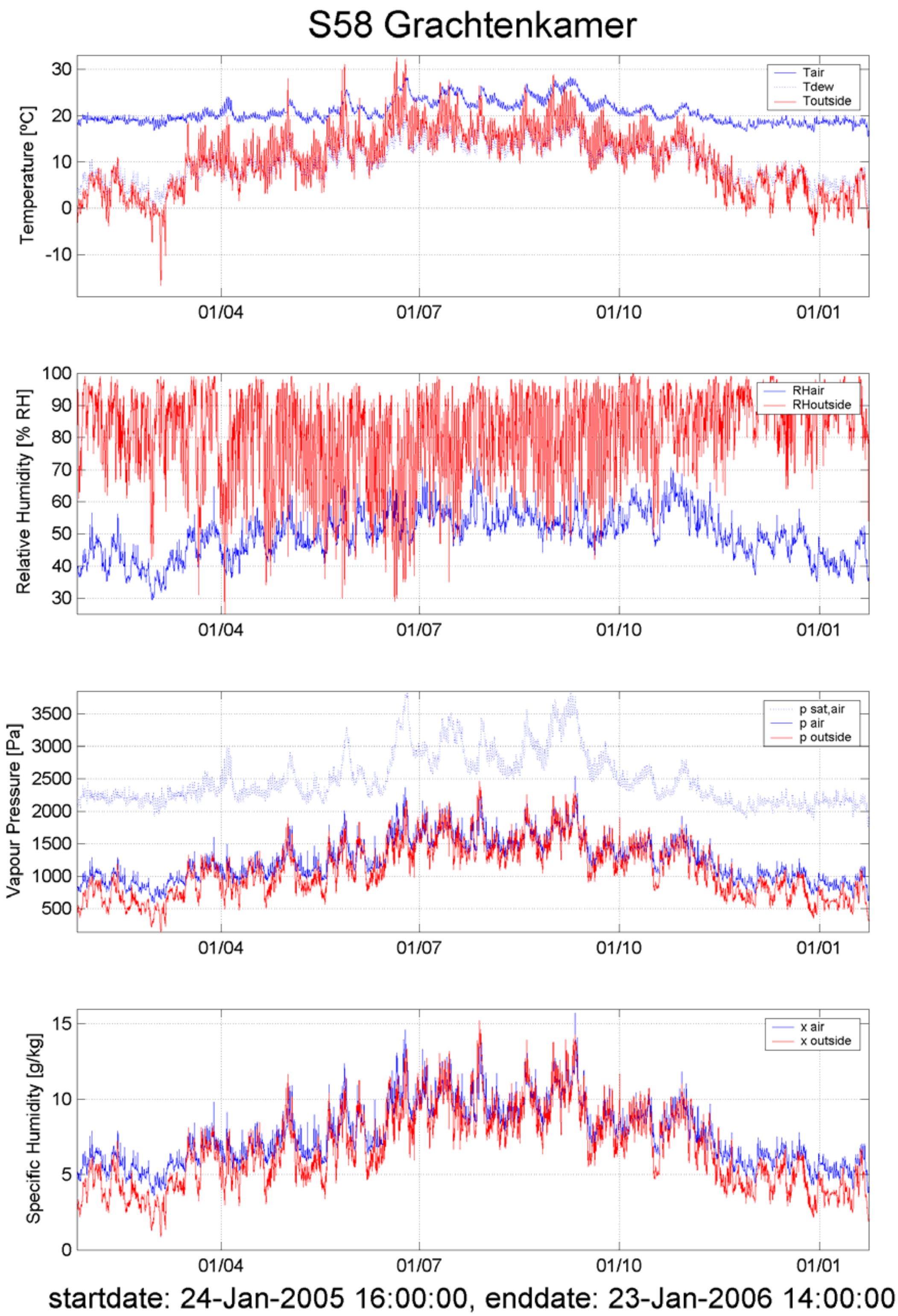


Figure 43 The above graph plots T and RH versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

S58 Canal Room

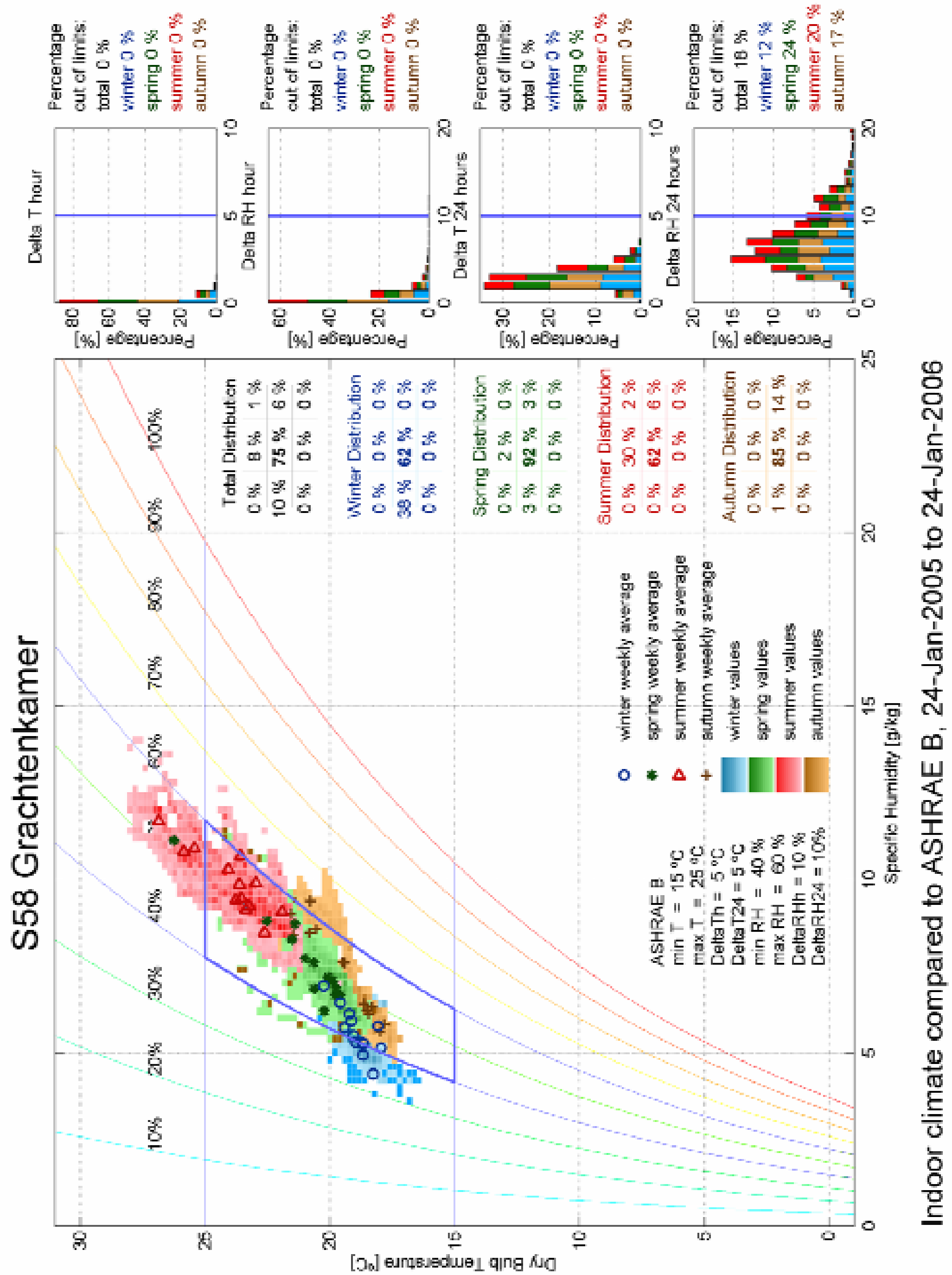


Figure 44 The measured values as recorded on the Mollier diagram, with a record of the hourly and daily fluctuations in T and RH on the right.

Antechamber above the reception desk

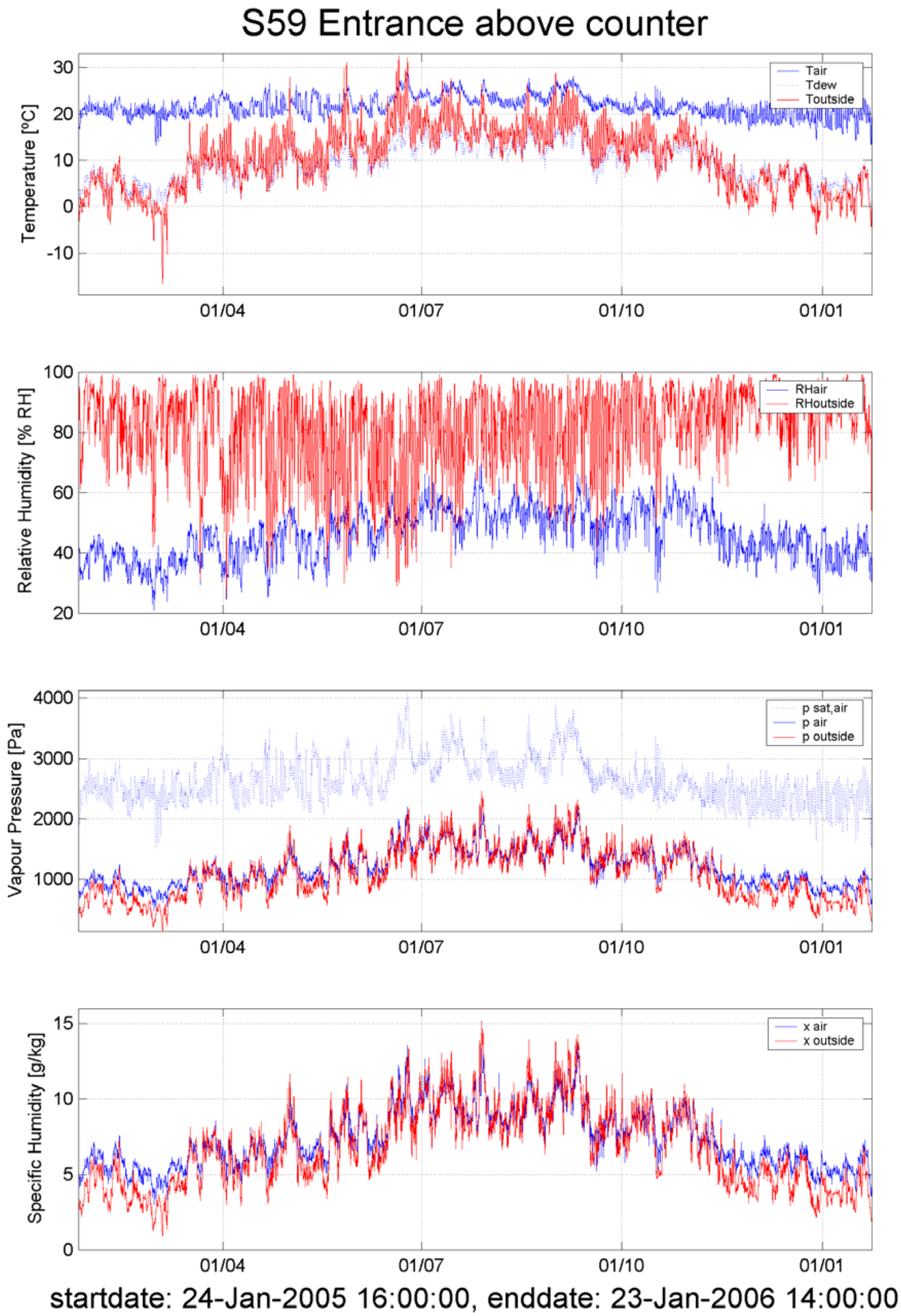


Figure 45 The graphs above plot the measured T and RH versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

S59 Antechamber above reception desk

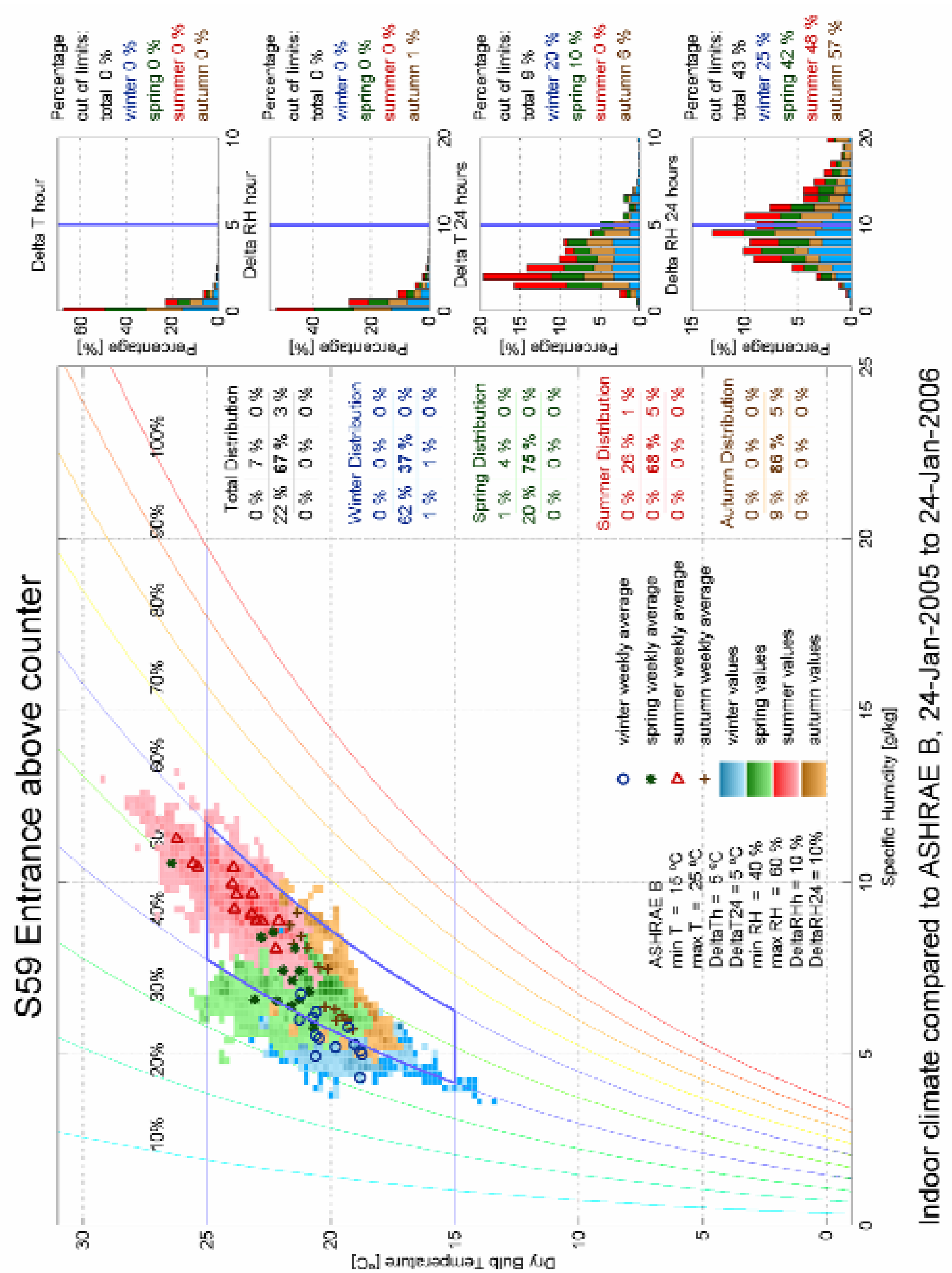


Figure 46 The measured values as recorded on the Mollier diagram, with on the right a record of the hourly and daily fluctuations in T and RH

Outside

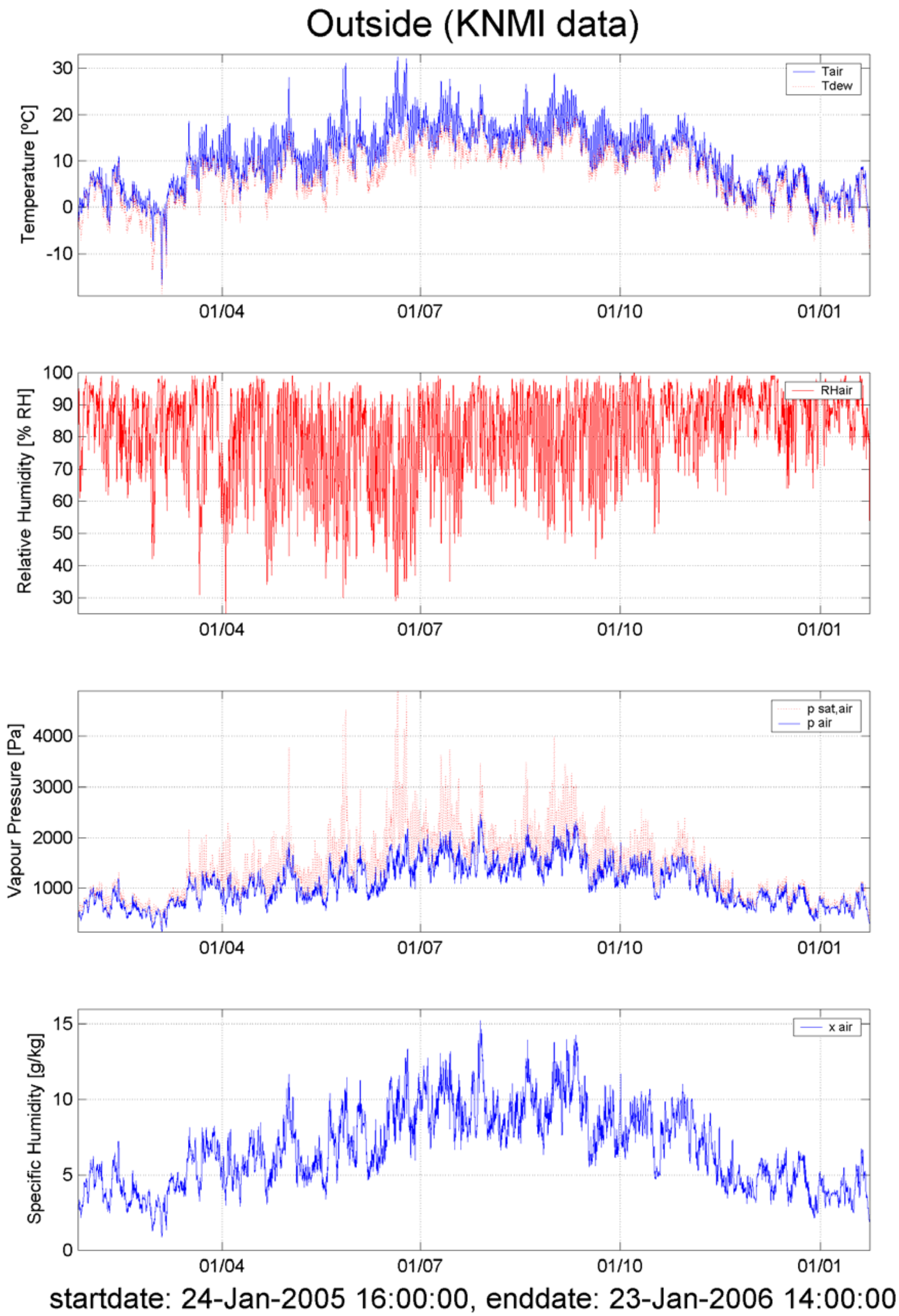


Figure 47 The graphs above plot the measured T and RH versus time. The calculations also give the values for the absolute moisture content and vapor pressure.

Outside (KNMI data)

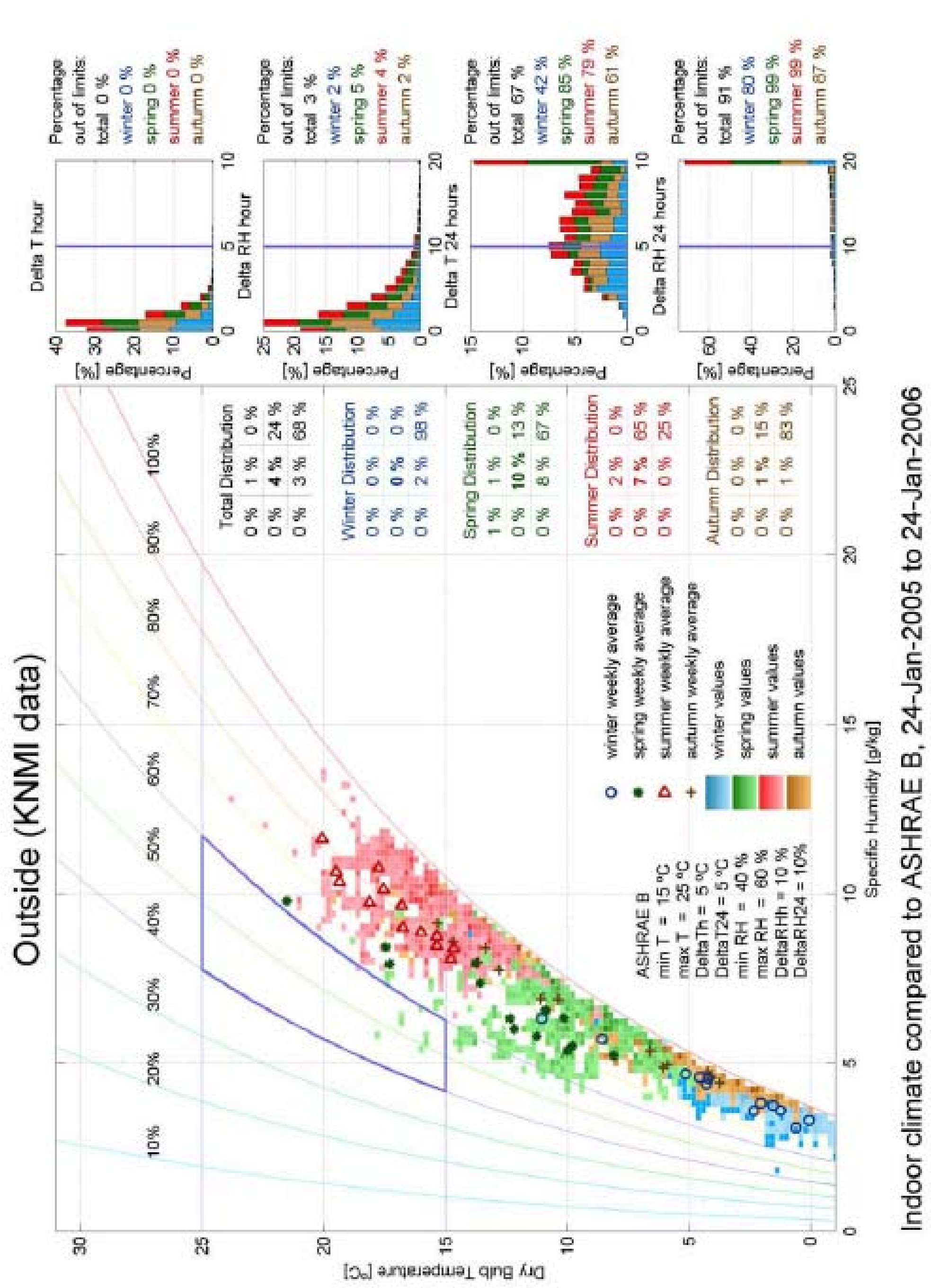


Figure 48 The measured values as recorded on the Mollier diagram, with a record of the hourly and daily fluctuations in T and RH on the right.

Beam head in the vestry cupboard

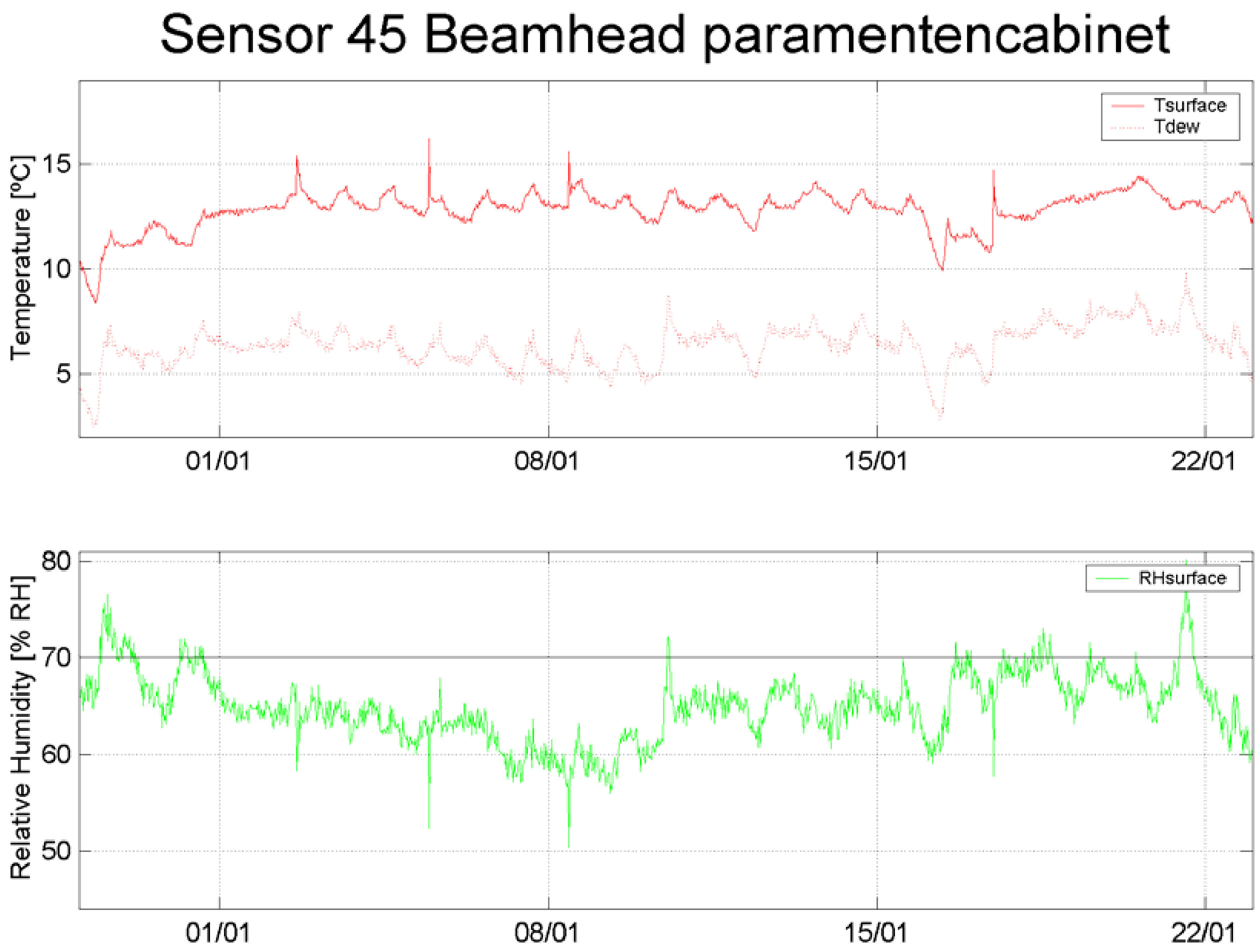


Figure 49 The graph above plots the measured T and the calculated RH versus time on the surface of the beam head in the vestry cupboard. The lower graph also shows the 70% line of increased risk of microbial growth [5].

Church wall surface, north side

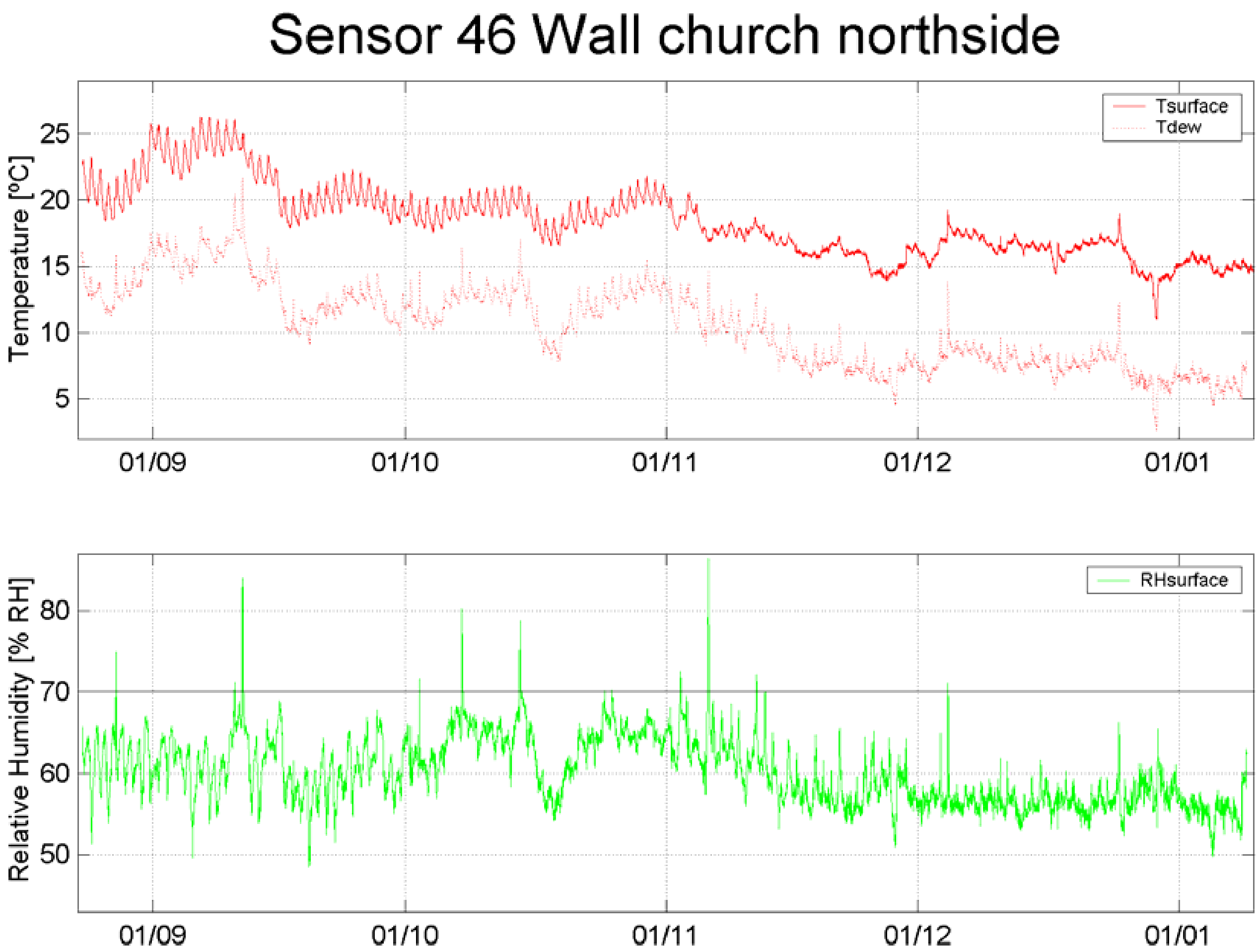


Figure 50 The graph above plots the measured T and the calculated RH versus time on the surface of the church's north wall. The lower graph also shows the 70% line of increased risk of microbial growth.

Church window surface, north side

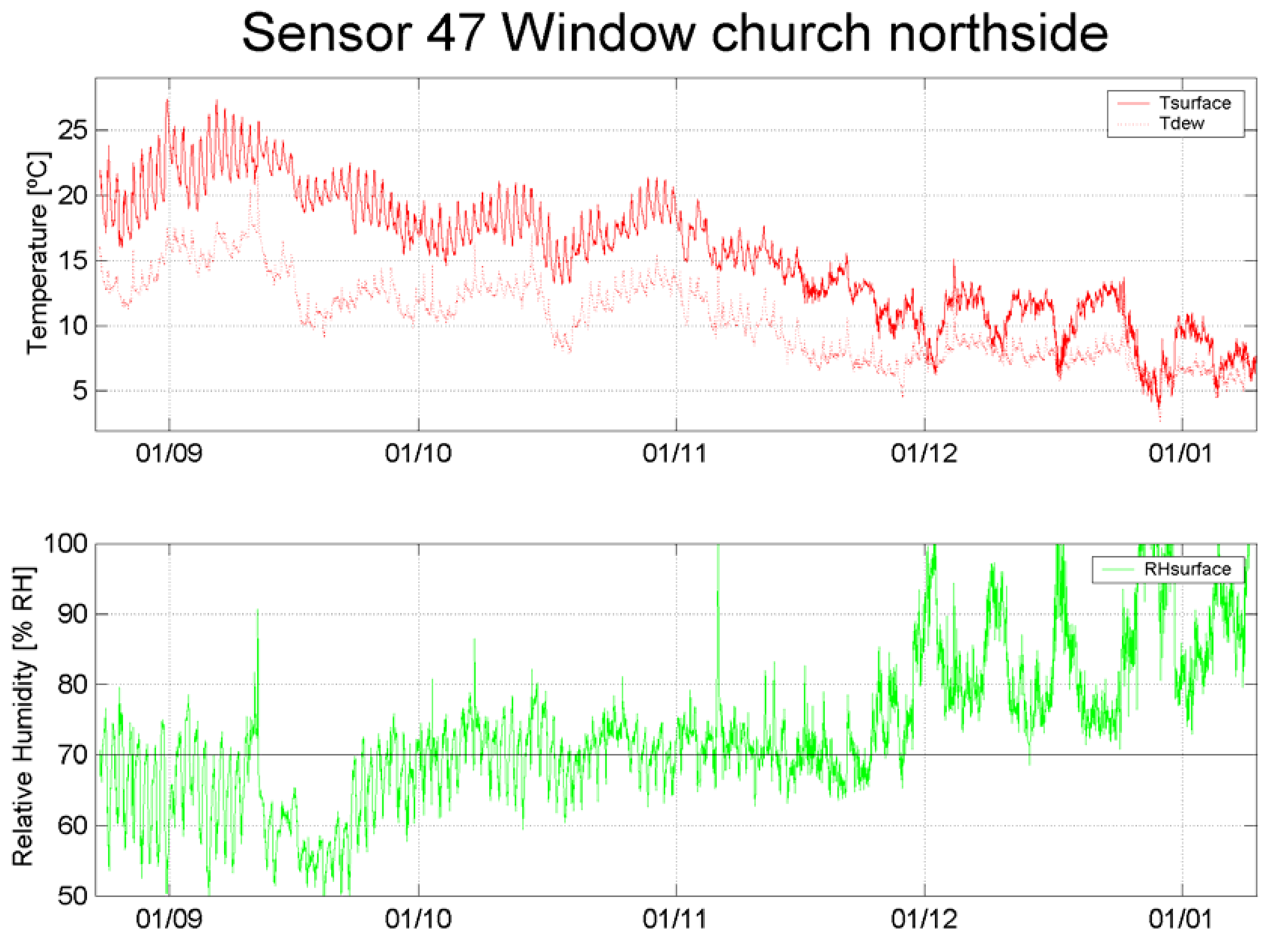


Figure 51 The graph above plots the measured T and the calculated RH versus time on the surface of the glass in the north wall of the church. The lower graph also shows the 70% line of increased risk of microbial growth.

Church window sill, north side

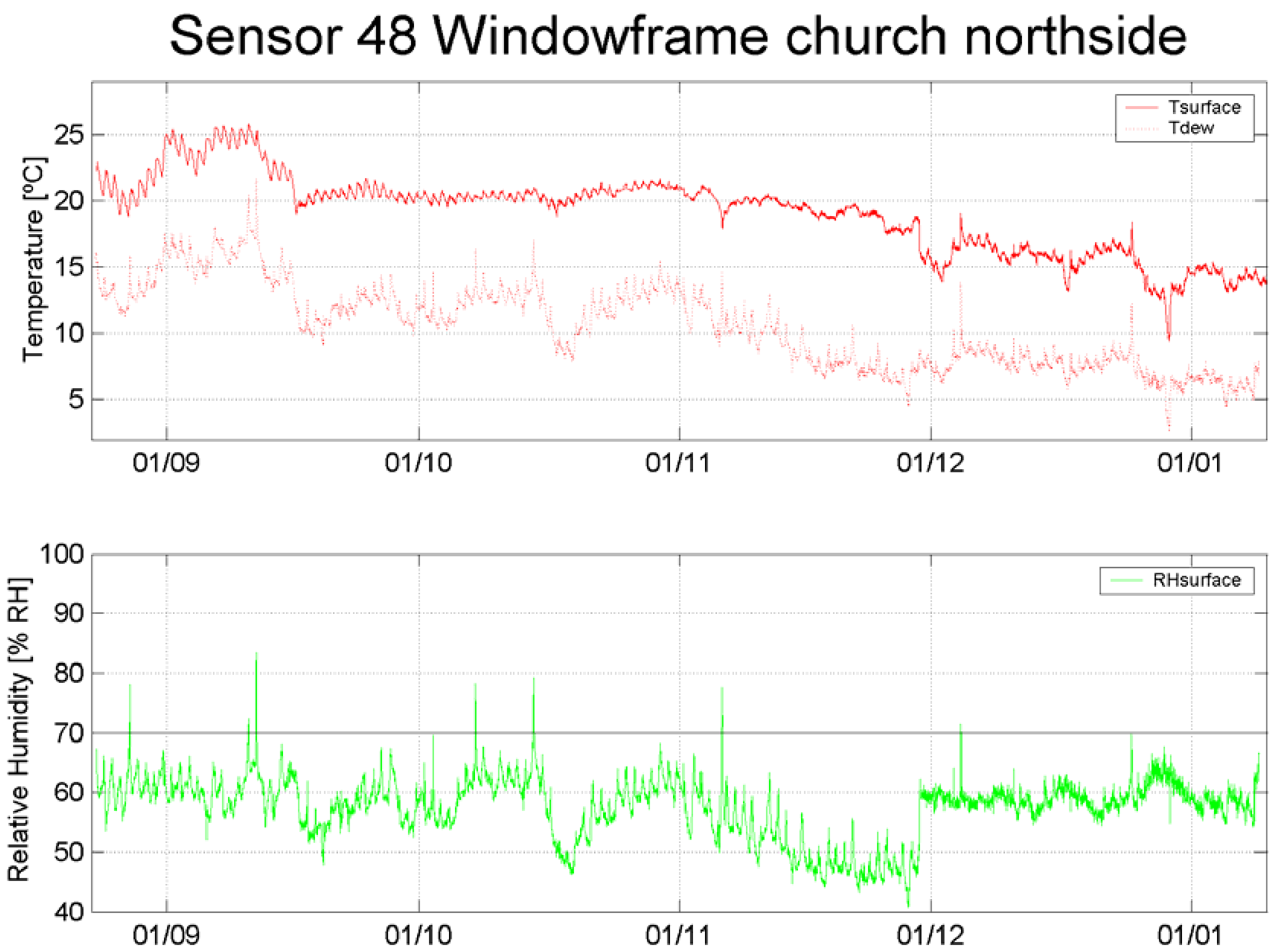


Figure 52 The graph above plots the measured T and the calculated RH versus time of the surface of the window sill on the north wall of the church. The lower graph also shows the 70% line of increased risk of microbial growth.

Stratification measurements below the Lamp of God

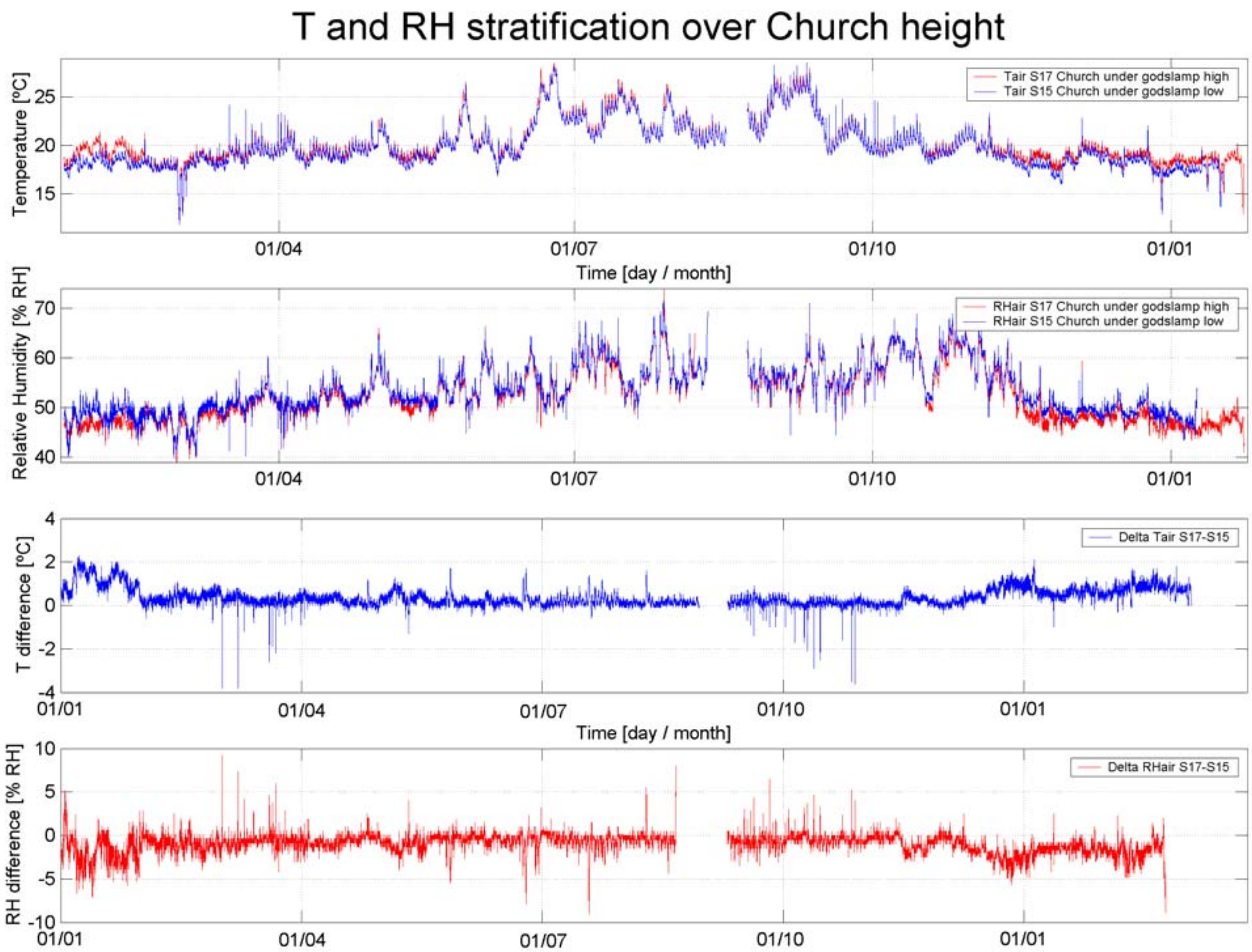


Figure 53 The graph above plots the T and RH measured by the upper and lower sensors plotted versus time. The two lower graphs represent the difference between the two sensors.

Appendix C: Thermo- and hygrograms

Presented in the following pages are the infrared thermograms for five locations in the museum, including the relevant hygrograms and an ordinary photograph of the location. These are relative to the following situations:

• Single pane glass with condensation on the 2nd floor in the exhibit room.
• A painting against a cold wall and a window sill with condensation on its surface on the 3rd floor, in the hallway behind the altar.
• A painting against a cold wall on the 3rd floor in the Church, the side wall near the altar.
• An art object against a cold wall on the 3rd floor, behind the altar.
• Beam head on the 4th floor, behind the altar near the stairs.

Single pane glass with condensation.

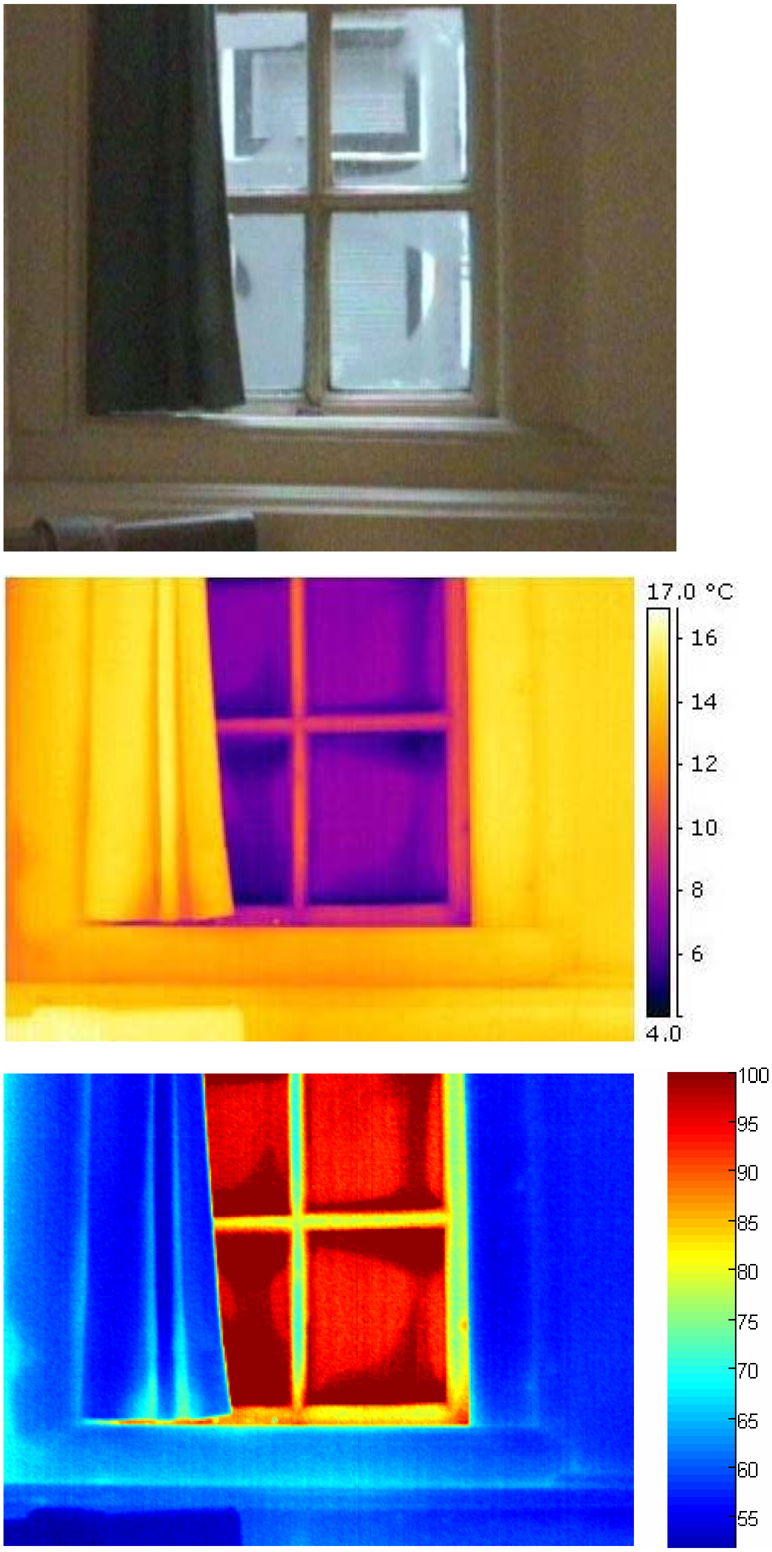


Figure 54 Ordinary, thermal and hygrographic images of a window with condensation on the 2nd floor in the exhibit room.

Painting against a cold wall and a window sill

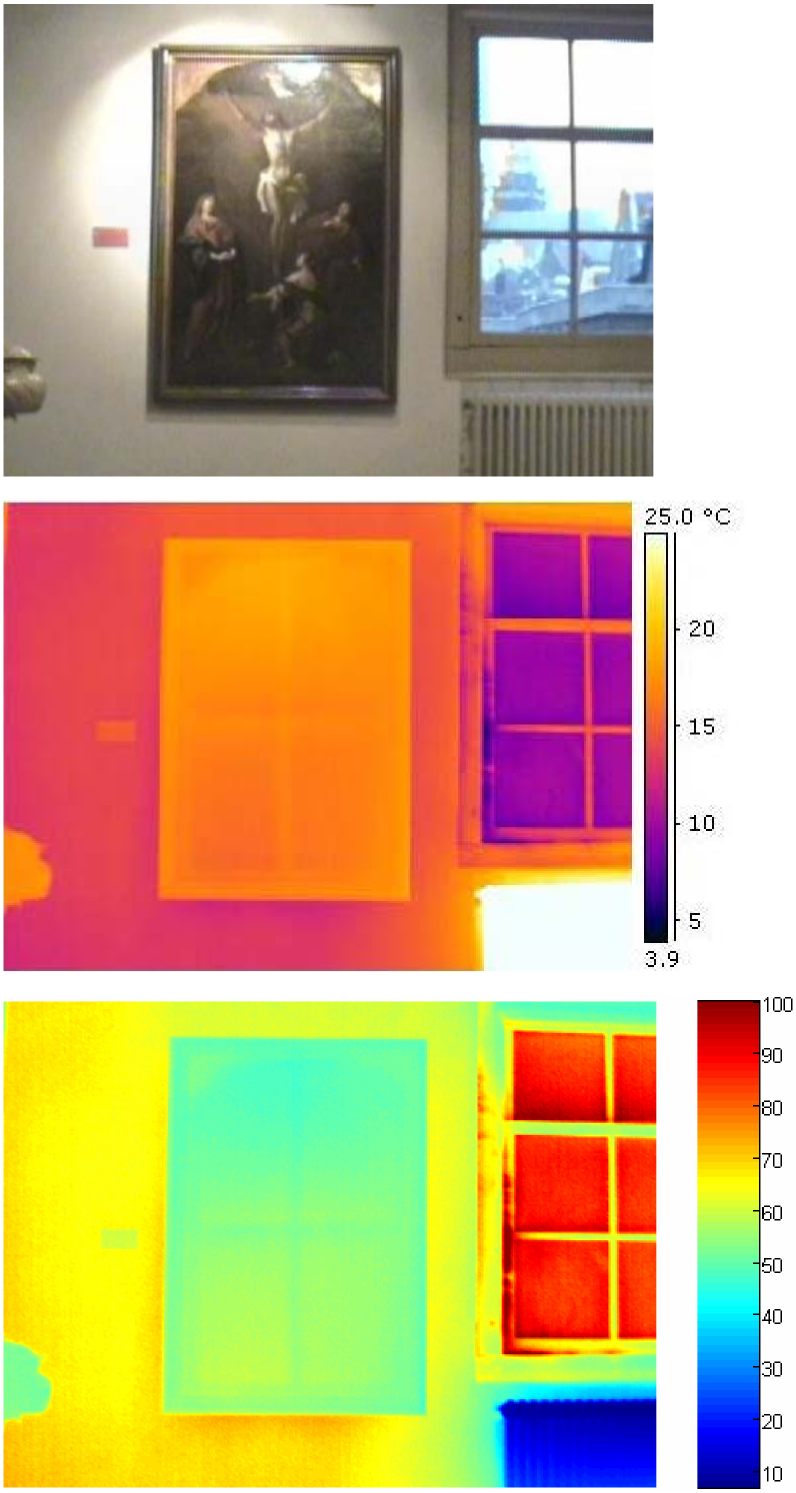


Figure 55 Ordinary, thermal and hygrographic images of a painting on the outside wall on the 3rd floor, in the hallway behind the altar.

Painting against a cold wall

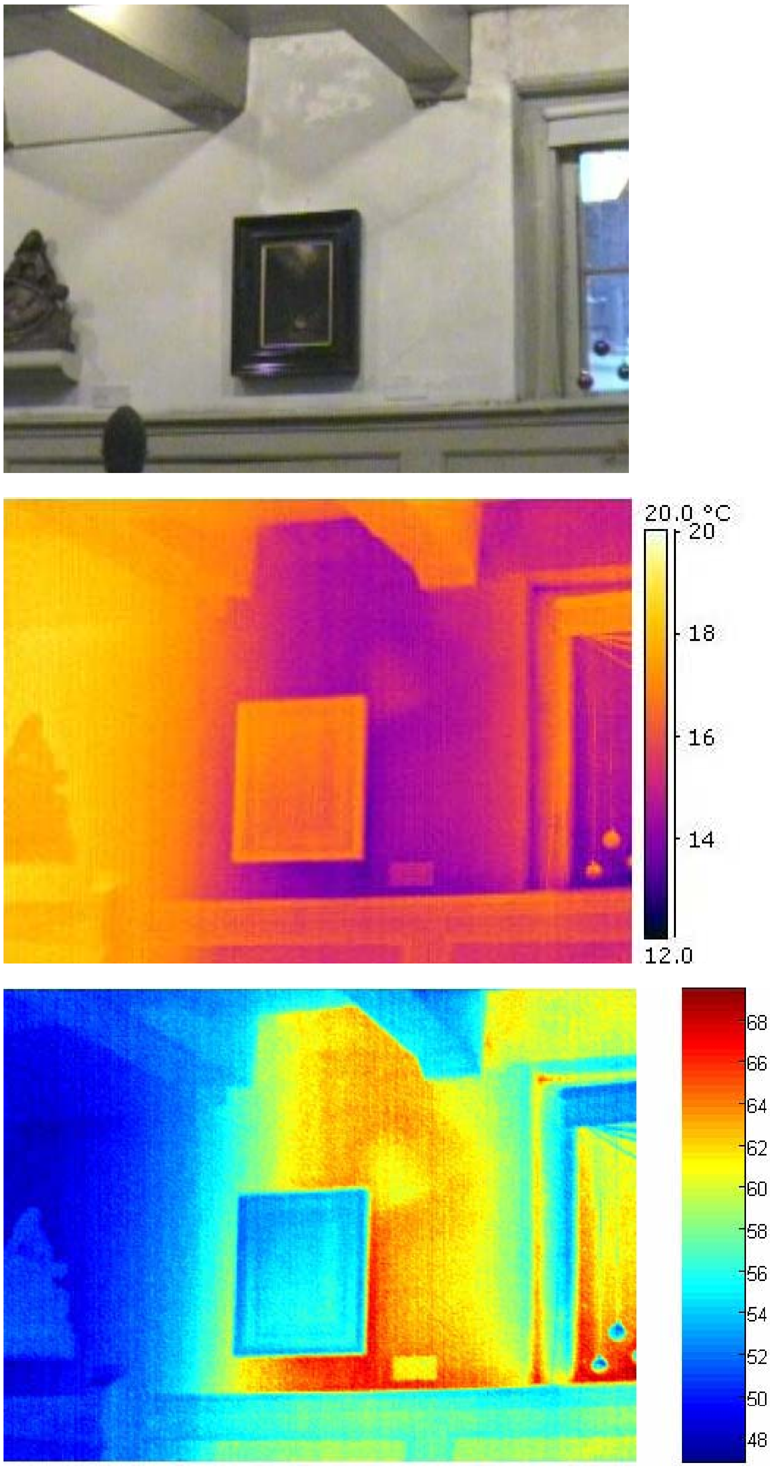


Figure 56 Ordinary, thermal and hygrographic images of a painting on a southern outside wall on the 3rd floor of the Church near the altar.

Art object against a cold outside wall

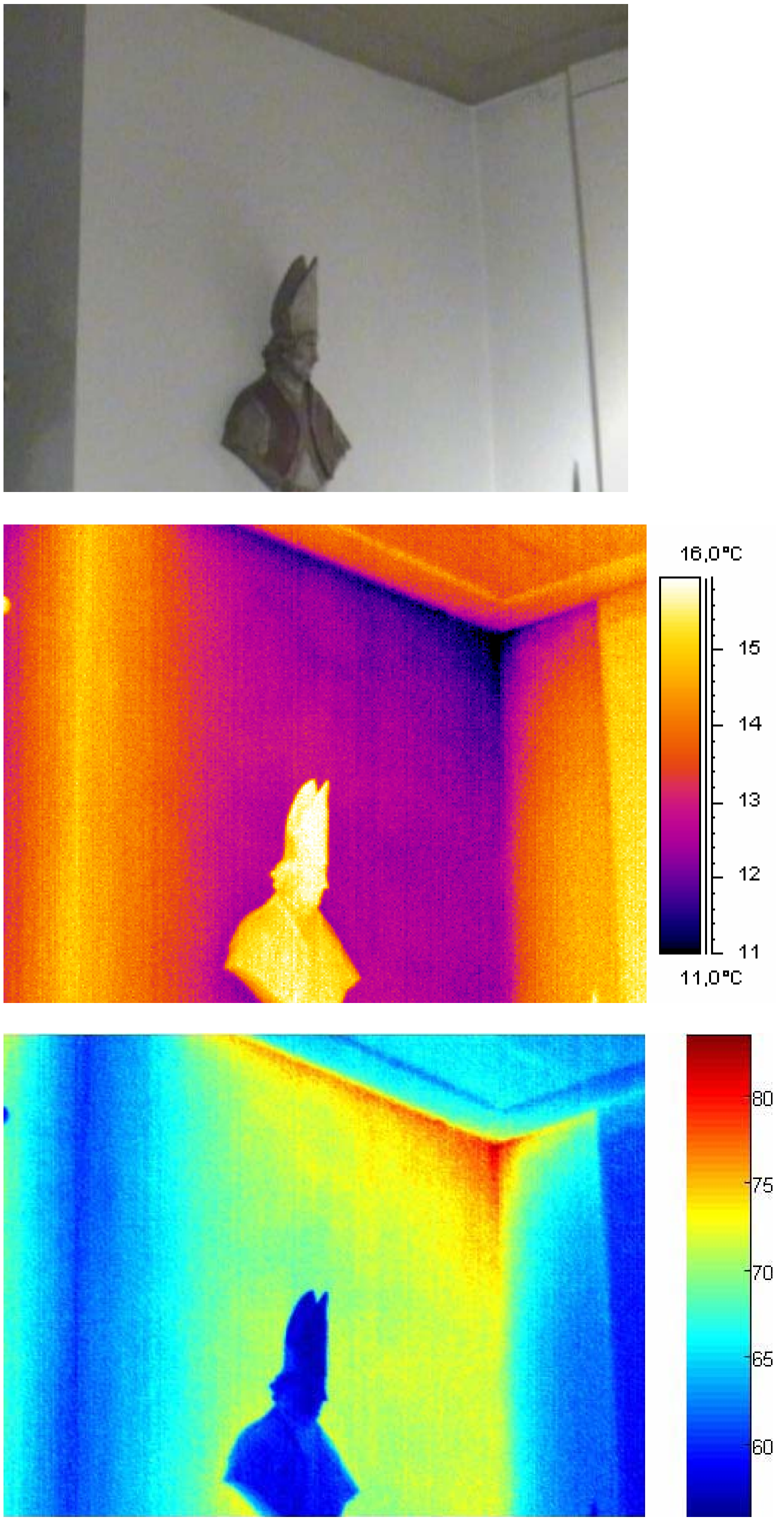


Figure 57 Ordinary, thermal and hygrographic image of an art object against a cold outside wall. Location: 3rd floor behind the altar.

Restored beam head

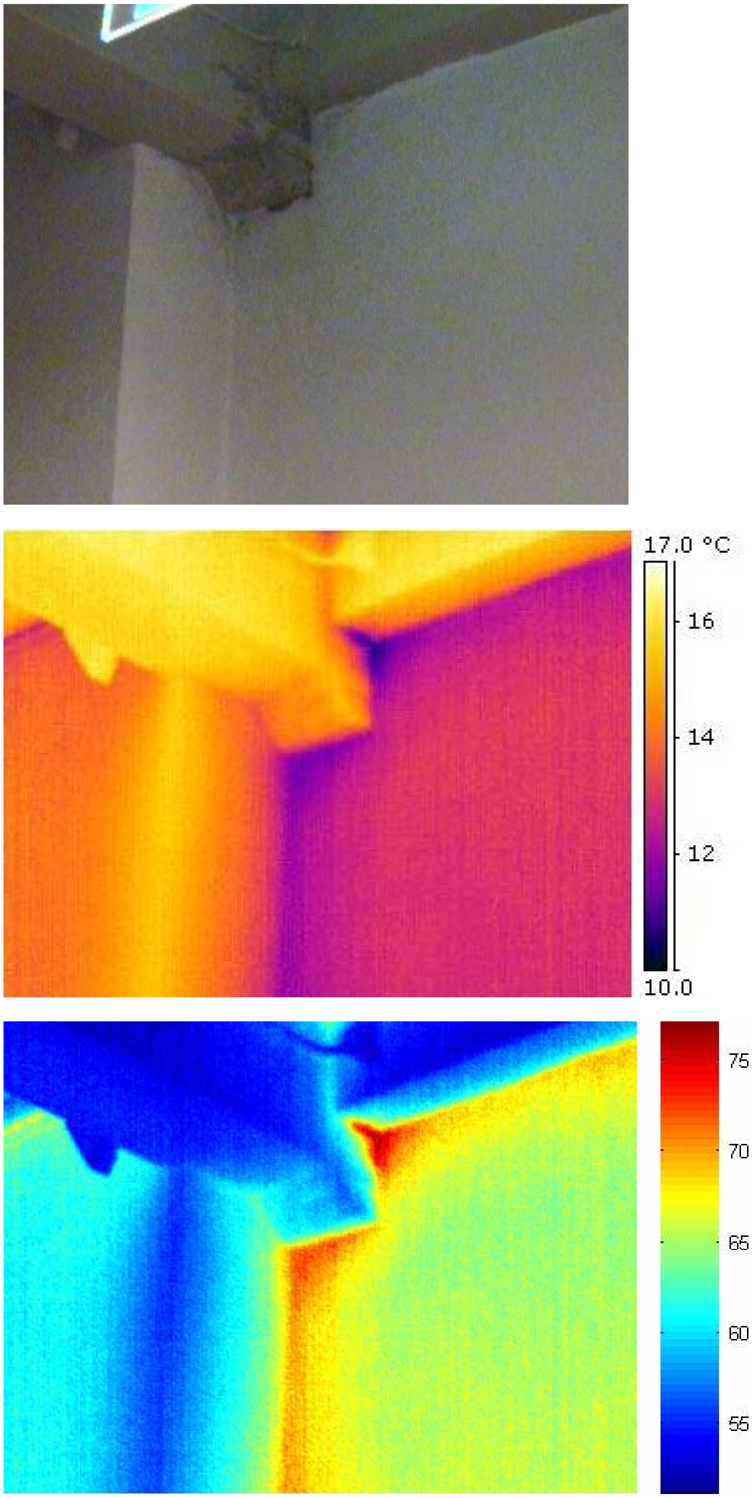


Figure 58 Ordinary, thermal and hygrographic images of a restored beam head. Location: 4th floor behind the altar near the stairs.

APPENDIX D: HAMBASE Results

This appendix presents in graphic form the results of the simulation study of the indoor climate of the Sael using HAMBASE. The simulation results below are given for the following:

• Simulation variant 1: the current situation
• Simulation variant 2: the situation without a humidifier or a dehumidifier
• Simulation variant 3: the situation without a humidifier or a dehumidifier but with ventilation
• Simulation variant 4: the situation with ventilation and dehumidification of the intake air.

Sael simulation variant 1 with validation

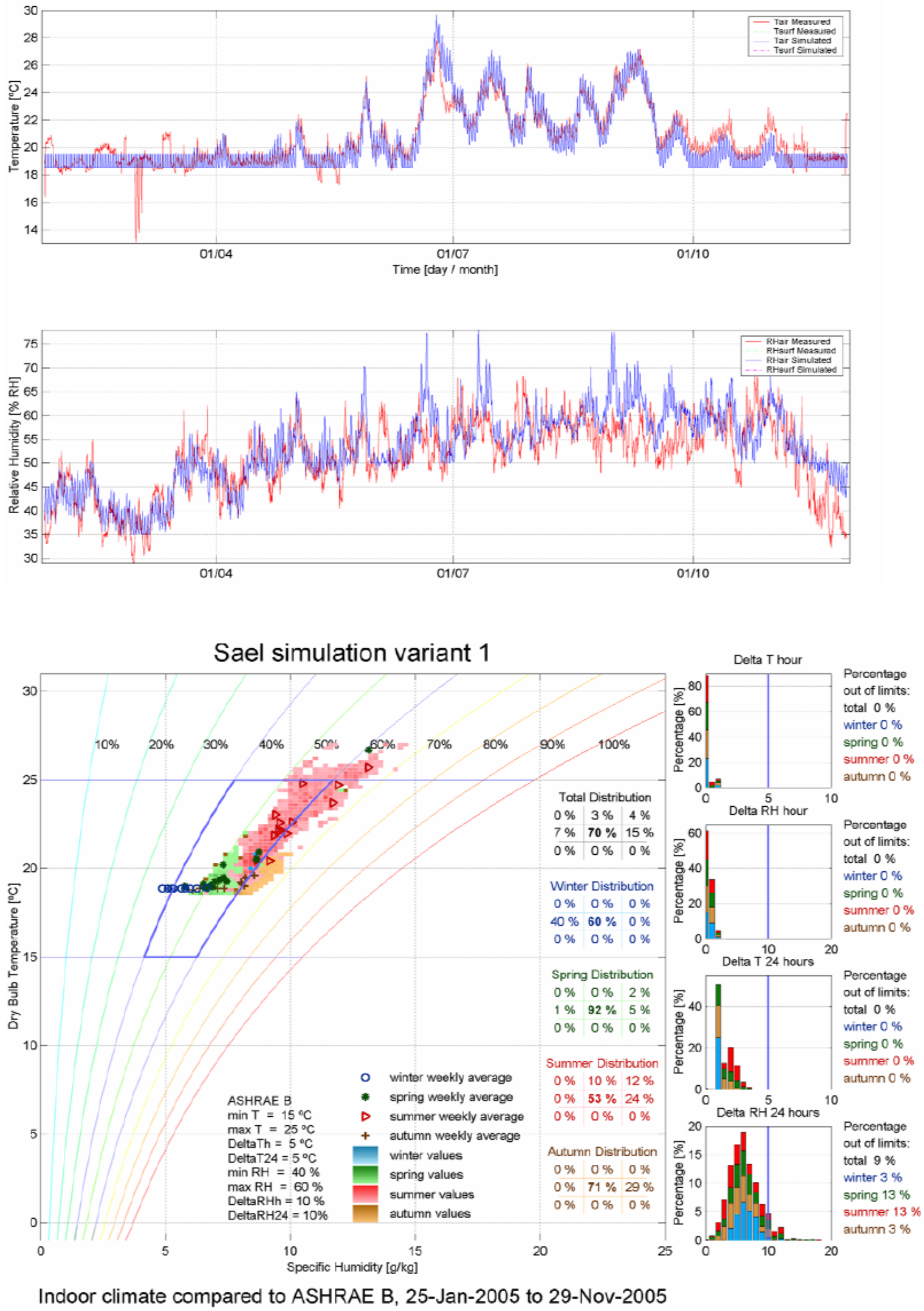


Figure 59 Presentation of the simulation results of variant 1. In the first graph the simulated temperature is plotted versus time, and measured values are also given for validation. The 2nd graph plots the measured and the simulated RH versus time. The 3rd graph records the measured values on a Mollier diagram and compares them with the Ashrae B climate requirements.

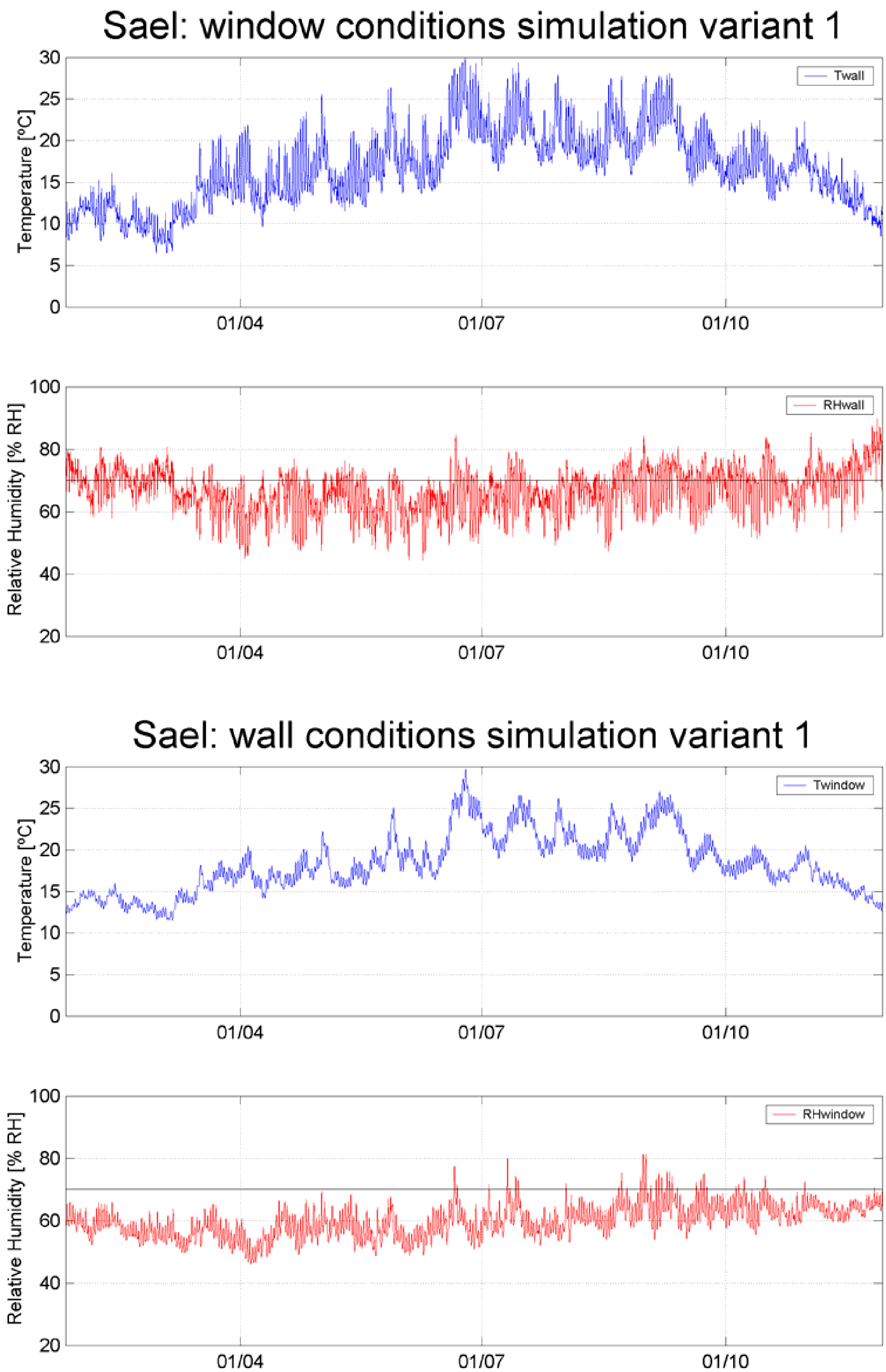


Figure 60 Presentation of the surface conditions of the glass and the inside wall of simulation variant 1.

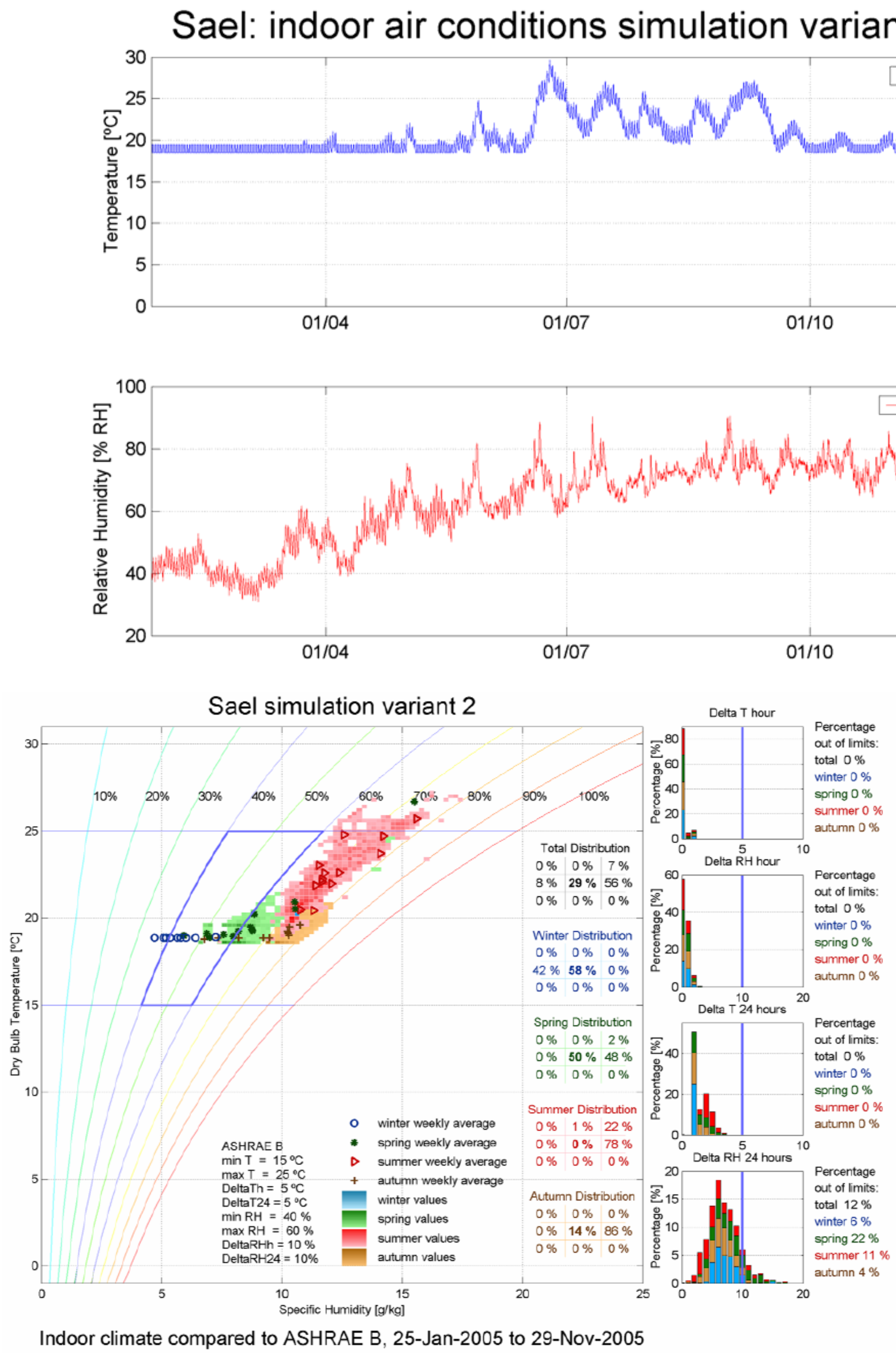


Figure 61 Presentation of the simulation results of variant 2. The first graph shows the simulated temperature plotted versus time. The 2nd graph presents the measurements and the simulated RH plotted versus time. The 3rd graph records the measured values on a Mollier diagram and compares them with the Ashrae B climate requirements.

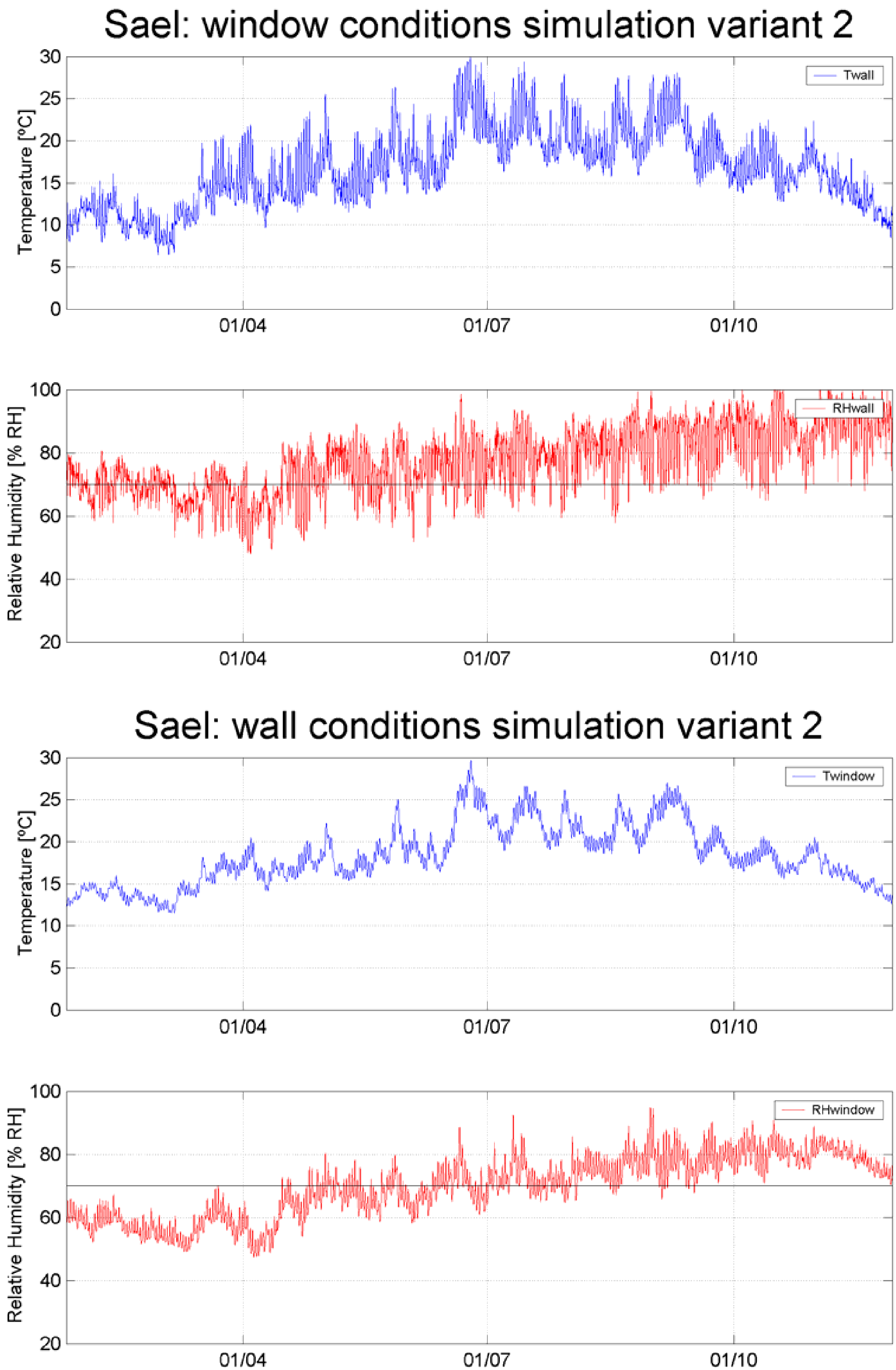


Figure 62 Presentation of the calculated T and RH at the surface of the outside wall in the Sael, simulation variant 2.

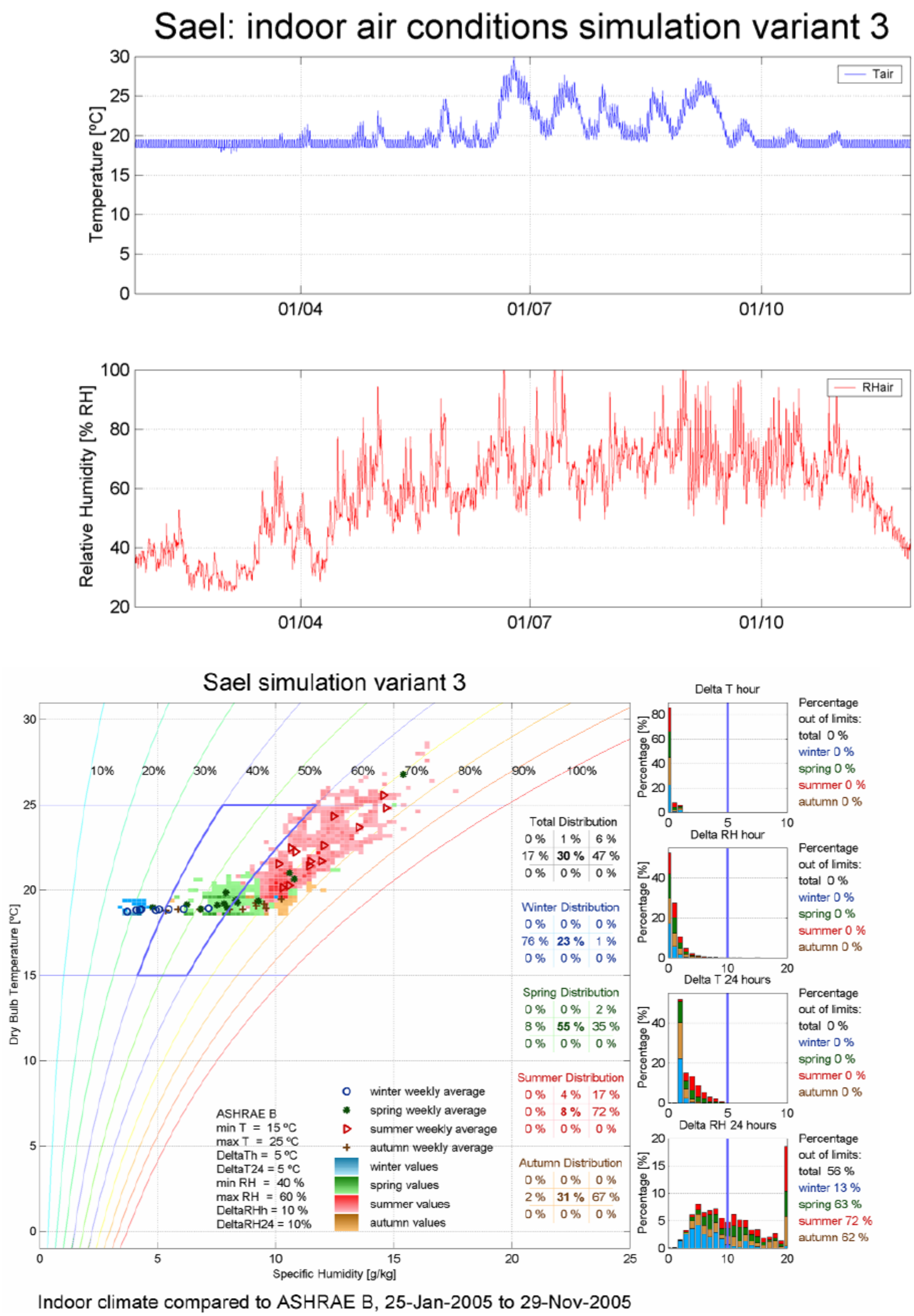


Figure 63 Record of the simulation results of variant 3. The first graph plots the simulated temperature versus time. The 2nd graph plots the measurements and the simulated relative humidity versus time. The 3rd graph records the measured values on a Mollier diagram and compares them with the Ashrae B climate requirements.

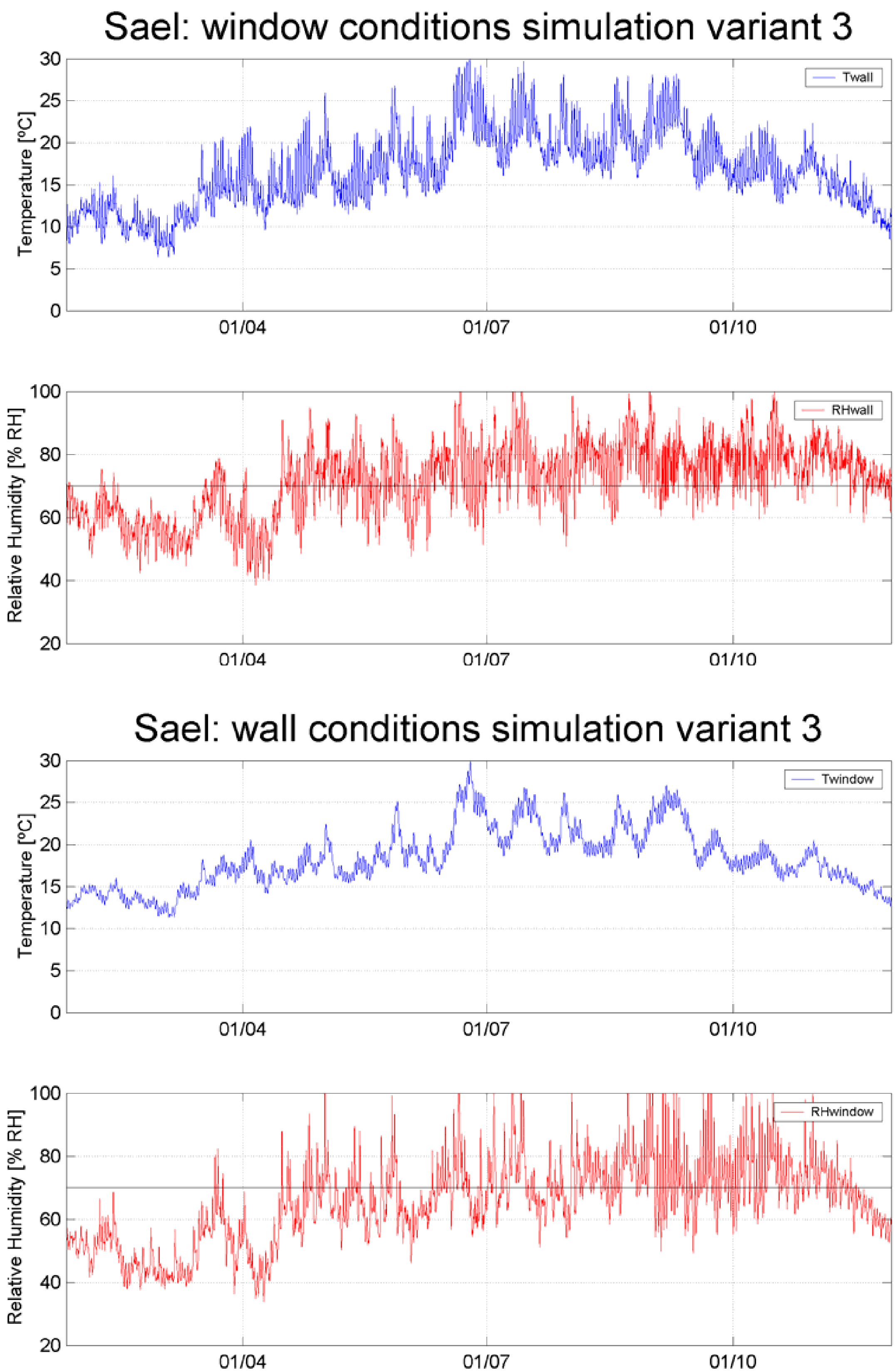


Figure 64 Presentation of the calculated T and RH at the surface of the outside wall in the Sael, simulation variant 3.

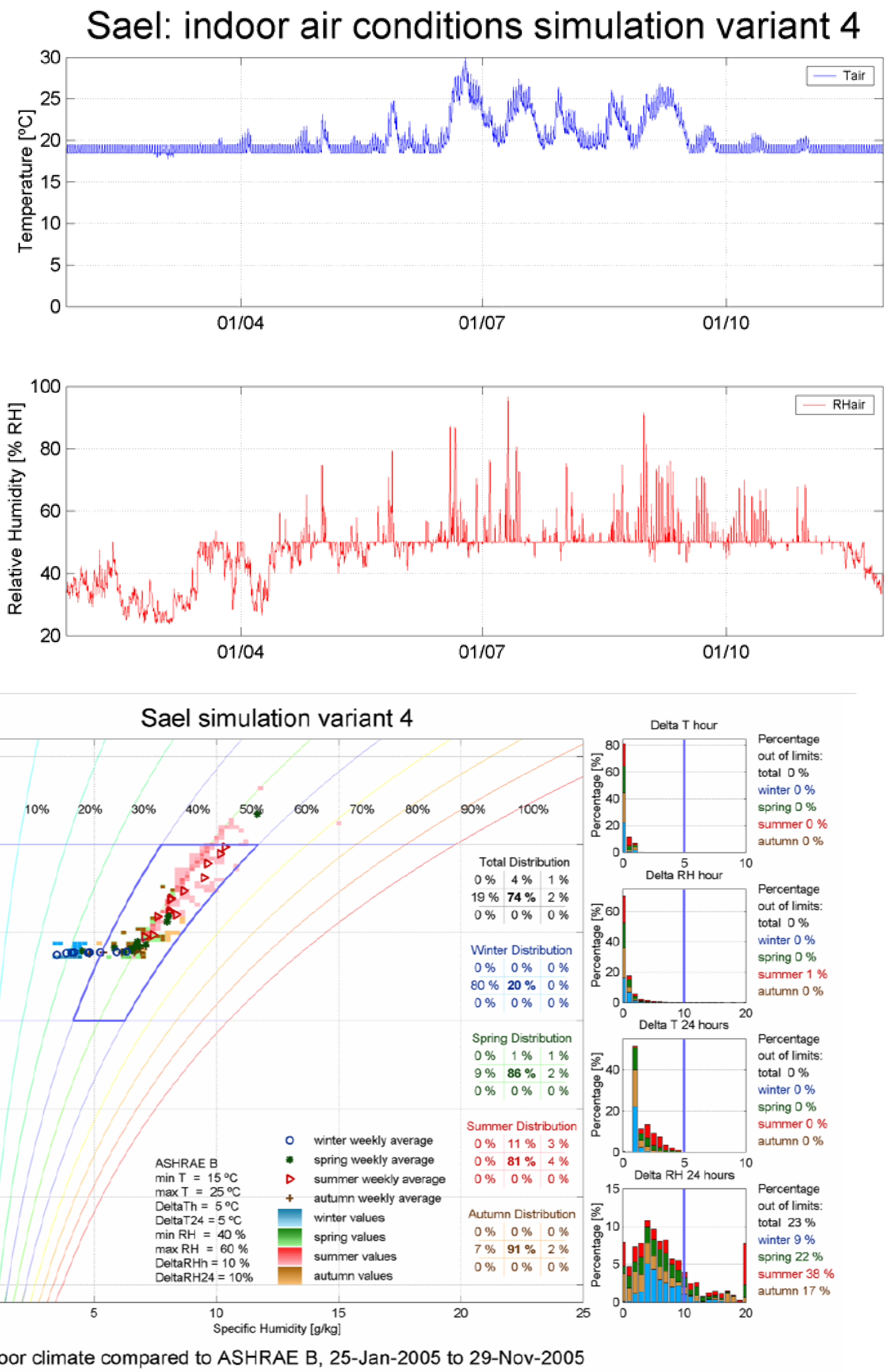


Figure 65 Presents the simulation results of variant 4. The first graph plots the simulated temperature versus time. The 2nd graph plots the measurements and the simulated relative humidity versus time. The 3rd graph records the measured values on a Mollier diagram and compares them with the Ashrae B climate requirements.

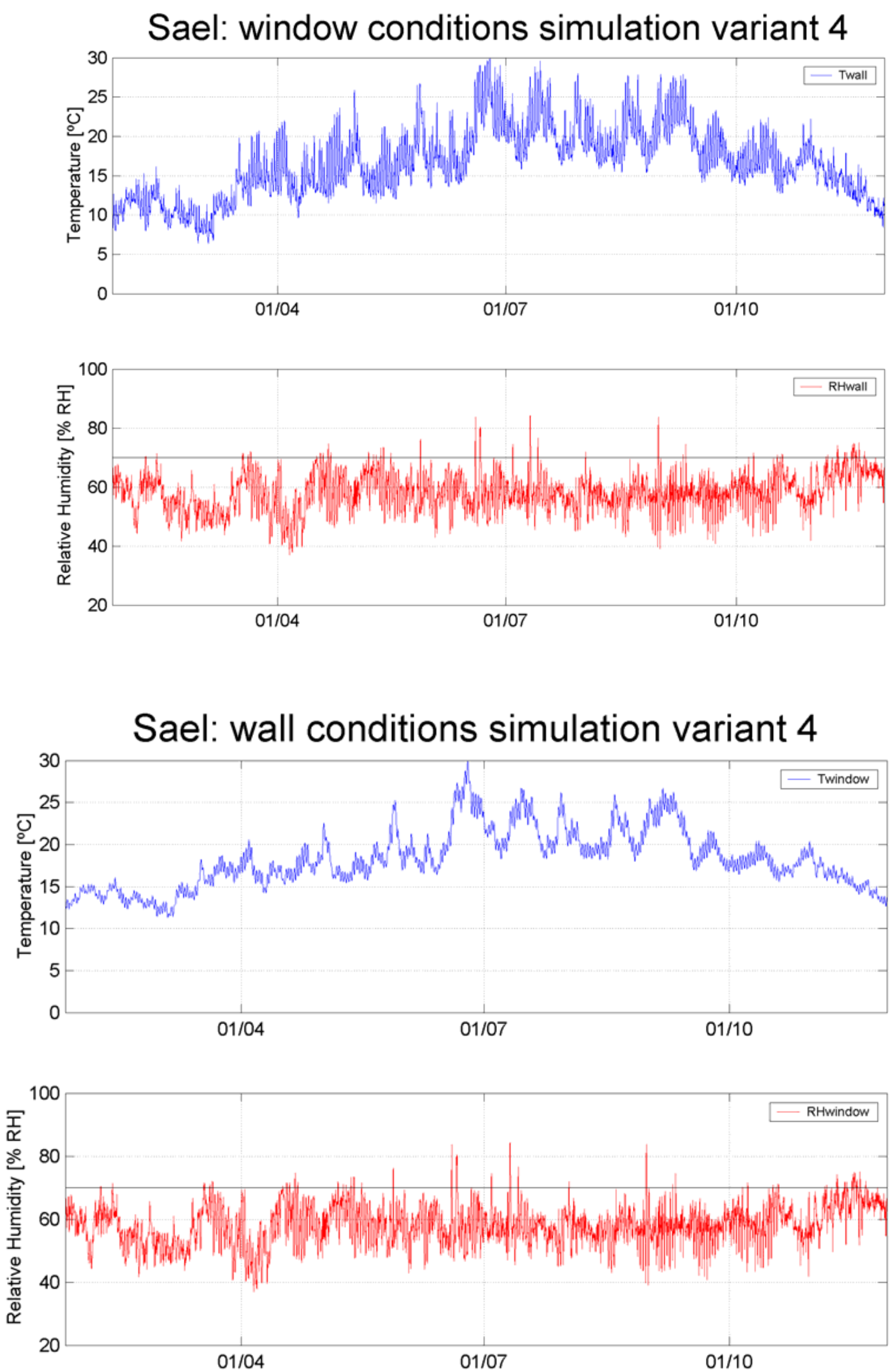


Figure 66 Presentation of the calculated T and RH at the surface of the outside wall in the Sael, simulation variant 4.

APPENDIX E: HAMBASE Input

[Key:
juli = July
buitenwand = external wall
betegelde vloer = tiled floor
plafond = ceiling
binnenwand noord/west = inside wall north/west
binnenwand noord/west = inside wall north/east
binnenwand noord/west = inside wall south/west
deur = door
enkel glas = single pane
wand noord/oost = wall north/east
wand zuid/oost = wall south/east
wand zuid/west = wall south/west
wand noord/west = wall north/west
vloer/plafond = floor/ceiling]

```
% ------------------------------------------------------------------------
% HAMBASE
%
% HEAT And Moisture Building And Systems Evaluation
% ------------------------------------------------------------------------
%
% Sael Amstelkring
% E.Neuhaus
% juli 2005
global InClimate Output
clear all
a=findobj('name',figure);
delete (a)
% ------------------------------------------------------------------------------
% PART 1 : THE CALCULATION PERIOD
% ------------------------------------------------------------------------
% FORMAT BASE.Period=[yr,month,day,ndays]
%
% yr = start year
% month = start
% month day = start day
% ndays = number of days simulated
BASE.Period=[2005,1,25,308];
BASE.DSTime=1;
% ------------------------------------------------------------------------ ---
% PART 2 : THE BUILDING
% ------------------------------------------------------------------------ ---
% ZONES NUMBERS [-] & VOLUMES [m3]
BASE.Vol{1}= 195;
% ** CONSTRUCTION COMPONENTS DATA **
% BASE.Con{conID}= [Ri, d1, matID,... , dn, matID, Re,ab, eb ].
BASE.Con{1} = [0.13, 0.3, 232, 0.04,0.5,0.9]; %buitenwand
BASE.Con{2} = [0.13, 0.02, 203, 0.05,502, 0.13,0.5,0.9]; %betegelde vloer
BASE.Con{3} = [0.13, 0.08, 501, 0.13,0.5,0.9]; %plafond
BASE.Con{4} = [0.13, 0.3, 232, 0.13,0.5,0.9]; %binnenwand noord/west
BASE.Con{5} = [0.13, 0.1, 502, 0.13,0.5,0.9]; %binnenwand zuid/oost
BASE.Con{6} = [0.13, 0.35, 232, 0.13,0.5,0.9]; %binnenwand zuid/west
BASE.Con{7} = [0.13, 0.04, 503, 0.04,0.8,0.9]; %deur
% ** GLAZING SYSTEMS DATA**
%BASE.Glas{glaID}= [Uglas, CFr, ZTA, ZTAw, CFrw, Uglasw]
BASE.Glas{1}= [1.6, 0.047, 0.65, 0.072, 0.116, 3.6 ]; %dub.begl.StGobain 04 polygl HR+
BASE.Glas{2}= [3., 0.11, 0.26, 0.31, 0.34, 2.8 ]; %
BASE.Glas{4}= [3.6, 0.03, 0.1, 0.36, 0.36, 3.6 ]; %enkel glas
% ** ORIENTATIONS **
% FORMAT BASE.Or{orID}=[beta gamma]
% beta = tilt (vertical=90,horizontal=0)
% gamma = azimuth (east=-90, west=90, south=0, north=180)
%
%BASE.Or{orID}= [beta, gamma];
BASE.Or{1}= [90.0, -45.0 ]; %wand noord/oost
BASE.Or{2}= [90.0, -135.0 ]; %wand zuid/oost
BASE.Or{3}= [90.0, 45.0 ]; %wand zuid/west
BASE.Or{4}= [90.0, 135.0 ]; %wand noord/west
BASE.Or{5}= [0.0, 0.0 ]; %vloer/plafond
```

```
% **SHADOW DATA**
% Example input
%
BASE.shad{1}=[
1 0.07 5 1.6 0 0.5000 0.7 3;...
2 0.1 5.1 3.0000 17.00 0.0000 0 0;...
2 17.00 0.1 3.0000 0 5.1000 0 0;...
2 17.00 0.1 2.0000 0 0.0000 0 0;...
2 0.5 24.0 9.2000 34.10 -9.0000 0 0;...
3 1.25 1.25/7 2.75 15.50 0.0 0 0;...
3 1.50 1.50/7 1.50 12.70 1.50 0 0;...
4 0 10 20 30 50 60 90;...
5 1 0.9 0.8 0.7 0.6 0.5 0.4];
BASE.shad{2}=[
4 0 0 00 00 00 00 00;...
5 0 0 0 0 0 0 0];
% Changing '0' into '1' below, gives for one shadow ID-number a drawing of the
% obstacle geometry.
if 1==0
shaID=2;
figure(1)
shaddrawf1101(BASE.shad,shaID);
end
% I. EXTERNAL WALLS
%BASE.wallex{exID}= [zonenr, surf, conID, orID, bridge ]
BASE.wallex{1}= [1, 34.3, 1, 1, 0 ]; %buitenwand noord/oost
% II. WINDOWS IN EXTERNAL WALLS
%BASE.window{winID}= [exID, surf, glaID, shaID ]
BASE.window{1} = [1, 10, 4, 0 ]; %ramen noord/oost
% III. CONSTANT TEMPERATURE WALLS
%BASE.walli0{i0ID}= [zonenr, surf, conID, temp, bridge ]
%BASE.walli0{1}= [1, 35, 2, 10, 0 ]; %vloer
%BASE.walli0{2}= [1, 35, 3, 10, 0 ]; %plafond
% IV ADIABATIC EXTERNAL WALLS
%
% Each adiabatic wall gets an ID: iaID=1,2,...
% FORMAT wallia{iaID} = [zonenr,surf,conID];
% zonenr = select zone number from ZONES Section
% surf = total surface area in m2
% conID = select construction ID-number from CONSTRUCTION Section.
%BASE.wallia{iaID}= [zonenr, surf, conID]
BASE.wallia{1} = [1, 35, 2 ]; %vloer
BASE.wallia{2} = [1, 35, 3 ]; %plafond
BASE.wallia{3} = [1, 30.5, 5 ]; %wand zuid/oost
BASE.wallia{4} = [1, 34.3, 6 ]; %wand zuid/west
BASE.wallia{5} = [1, 30.5, 6 ]; %wand noord/west
% V. INTERNAL WALLS BETWEEN AND IN ZONES
%BASE.wallin{inID}= [zonenr1,zonenr2, surf, conID]
%BASE.wallin{1} = [1, 3, 12.5, 5]; %tussenvloer zolder en ruimte oost
%BASE.wallin{2} = [2, 3, 12.5, 5]; %tussenvloer zolder en ruimte west
%BASE.wallin{3} = [1, 2, 18.8, 8]; %tussenwand testruimten
```

[Key:
buitenwand noord/oost = outside wall north/east
ramen noord/oost = windows north/east
vloer = floor
plafond = ceiling
wand zuid/oost = wall south/east
wand zuid/west = wall south/west
wand noord/west = wall north/west
tussenvloer zolder and ruimte oost = mezzanine attic and room east
tussenvloer zolder en ruimte west = mezzanine attic and room west
tussenwand testruimten = partitions test areas]

[Key:
warmtebel. = heat loading
personen = persons]

```
%-------------------------------------------------------------------------- --
% PART 3 : profiles for internal sources, ventilation, sunblinds and free
% cooling
% -------------------------------------------------------------------------- ---
% **PROFILES**
% BASE.Ers{proID} = irradiance level for sun blinds [W/m2]
% BASE.dayper{proID} = [hrnr1,hrnr2,hrnr3], the starting time of a new period
% BASE.vvmin{proID} = [. . . ], the ventilation [1/hr], for each period
% BASE.vvmax{proID} = [. . . ], the ventilation [1/hr] in case free cooling
% BASE.Tfc{proID} = [. . . ], treshold [oC] for free cooling, for each period
% BASE.Tsetmin{proID}= [. . . ], setpoint [oC] switch for heating, (in case of
% no heating choose -100)
% BASE.Tsetmax{proID} = [. . . ], setpoint [oC] switch for cooling, (in case
% of no cooling choose 100)
% BASE.Qint{proID} = [. . . ], internal heat gains [W]
% BASE.Gint{proID} = [. . . ], moisture gains [kg/s]
% BASE.RVmin{proID} = [. . . ], setpoint [%] switch humidification,(in case of no
% humidifcation choose -1)
% BASE.RVmax{proID} = [. . . ], setpoint [%] switch dehumidification,(in case
% of no dehumidifcation choose 101)
% proID=1 bijvoorbeeld verwarming op basis van comfort
BASE.Ers{1} =300;
BASE.dayper{1}= [ 0, 8, 10, 17, ];
BASE.vvmin{1}= [ 0.2, 1.2, 1.2, 1.2 ];
BASE.vvmax{1}= [ 0.2, 1.2, 1.2, 1.2 ];
BASE.Tfc{1}= [ 30, 30, 30, 30 ];
BASE.Qint{1}= [ 0, 0, 750, 0 ]; %int. warmtebel. o.b.v. verl/personen 350+400
BASE.Gint{1}= [ 0, 0, 0.00005, 0 ]; %vochtproductie o.b.v. 5 personen
BASE.Tsetmin{1}= [ 18.5, 19.5, 19.5, 18.5 ];
BASE.Tsetmax{1}= [ 100, 100, 100, 100 ];
BASE.RVmin{1}= [ 45, 45, 45, 45 ];
BASE.RVmax{1}= [ 50, 50, 50, 50 ];
% THE PROFILES OF THE BUILDING
% BASE.weekfun{zonenr} = [upnrmon, upnrtue, upnrwed, upnrthu, upnrfri, upnrsat, upnrsun]
BASE.weekfun{1}= [1, 1, 1, 1, 1, 1, 1 ];
%-------------------------------------------------------------------------- --
% PART 4 : Heating, cooling, humidification, dehumidification
% -------------------------------------------------------------------------- ---
% If the maximum heating capacity is known then that value can be used. If it is
% unknown the value '-1' means an infinite capacity. The value '-2' can be used
% for a reasonable estimate of the maximum heating capacity. If there is no
% cooling the dehumidification capacity is '0' Cooling and dehumification are
% negative! for each zone :
%
% FORMAT BASE.Plant{zonenr}=[heating capacity [W], cooling capacity [W],
% humidification capacity [kg/s],dehumidification capacity [kg/s]];
BASE.Plant{1}=[3000,0.0,0.0001,-0.0003];
% The simulation program treats radiant heat and convective heat differently.
% For each zone:
%
% FORMAT BASE.convfac{zonenr}=[CFh CFset CFint ];
% CFh =Convection factor of the heating system: air heating CFh=1,
% radiators CFh=0.8 floor heating CFh=0.5, cooling usually CFh=1
% CFset= Factor that determines whether the temperature control is on the air
% temperature (CFset=1), or comforttemperature (CFset=0.6),Tset=CFset*Ta+(1-CFset)*Tr
%
                    % CFint= is the convection factor of the casual gains (usually CFint=0.5)
```

```
BASE.convfac{1}=[0.9, 1, 0.5 ];
% If a heat recovery from ventilation air is used the effective temperature
% efficiency 'etaww' and the maximum indoor air temperature 'Twws' above which
% the heat exchanger will be by-passed must be known. In summer with cooling
% conditions this temperature is used to switch the exchanger on, e.g Twws=22oC
%
% FORMAT BASE.heatexch{zonenr}=[etaww, Twws];
BASE.heatexch{1}=[0 22];
BASE.heatexch{2}=[0 22];
BASE.heatexch{3}=[0 22];
BASE.heatexch{4}=[0 22];
% Real rooms are furnished. Furnishings are an important moisture storage.
% Moisture is released dependent on the change in relative humidity. Especially
% in zones with a lot of paper of textiles this can easily outweigh the moisture
% storage of the building. A value of '1' means that about the same amount is
% stored as in the air that fills the volume of the zone. The heat storage of
% furnishings is less important but by absorbing solar radiation and releasing
% that directly to the indoor air more solar energy is released in a convective
% way. A value for the convective fraction of 0.2 can be considered as
% reasonable. For each zone:
%
% FORMAT BASE.furnishings{zonenr}=[fbv CFfbi];
% fbv = Moisture storage factor
% CFfbi= The convection factor for the solar radiation due to furnishings.
BASE.furnishings{1}=[1, 0.2];
BASE.furnishings{2}=[1, 0.2];
BASE.furnishings{3}=[1, 0 ];
%****************** END OF INPUT***************************************************
%
% This input is now completely stored in the structured array BASE. By typing
% BASE in the command window, the input can be checked and changed
%
% In Hambasefun input is changed to an input the simulation program WAVO needs.
[Control,Profiles,InClimate,InBuil]=Hambasefun(BASE);
Xwavoextra1
% The advanced user can modify the files InClimate, InBuil,Profiles, Control
% (type help_wavooutput)
% Output containes all calculated data. Weather data are in InClimate. With
% these file the program wavoouput makes some plots. Type 'help_wavooutput' to
% see the explanation of the content of Output and of InClimate
[Output]=Xwavox1104(Profiles,InClimate,InBuil,Control);
xwavouitvoer0404
```

[Key:
uitvoer = output]

end

APPENDIX F: Results of the CFD analysis for the Sael

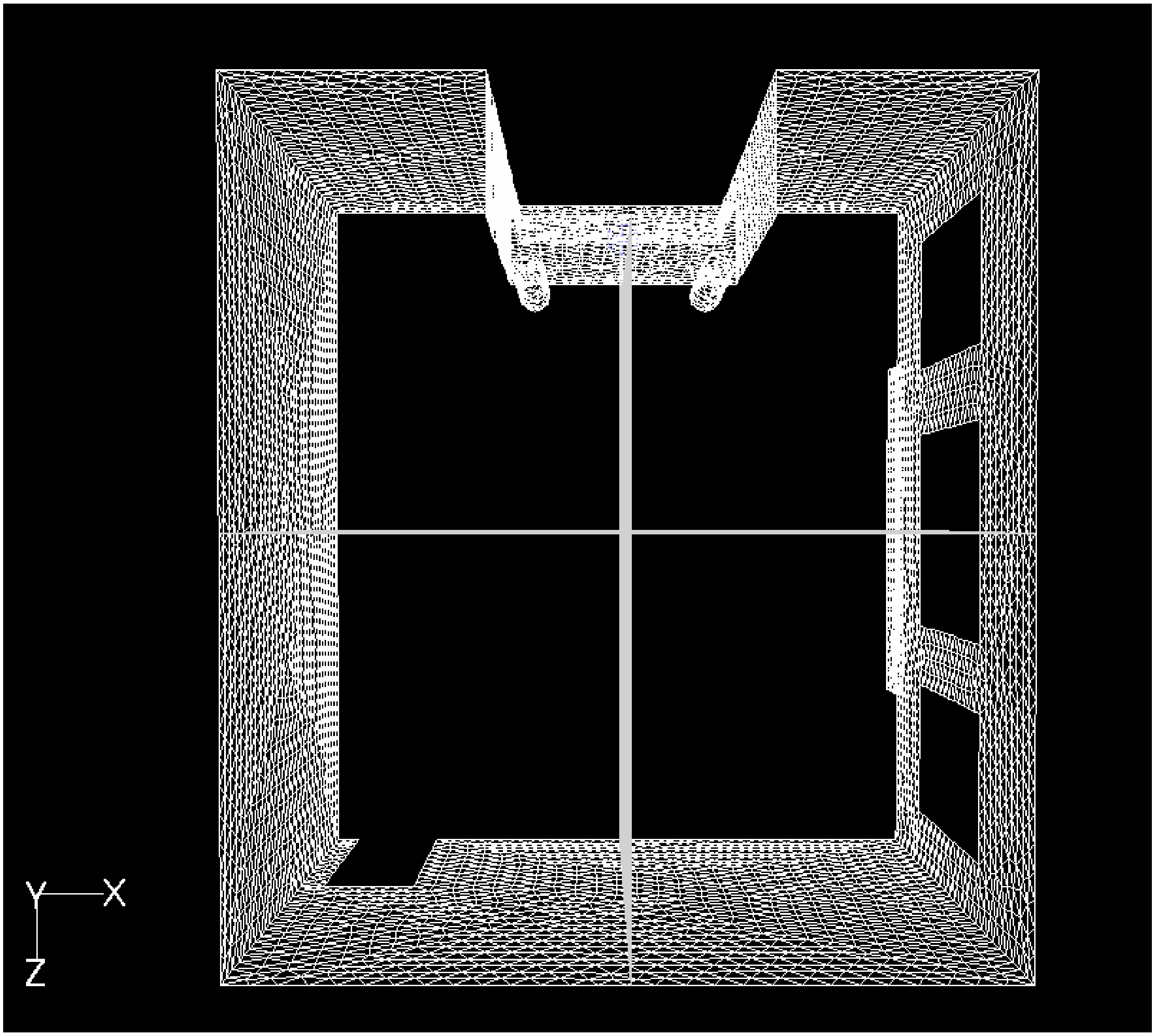


Figure 67 Plan view of the Sael, where the longitudinal cross-section is indicated by (1) and the width by (2).

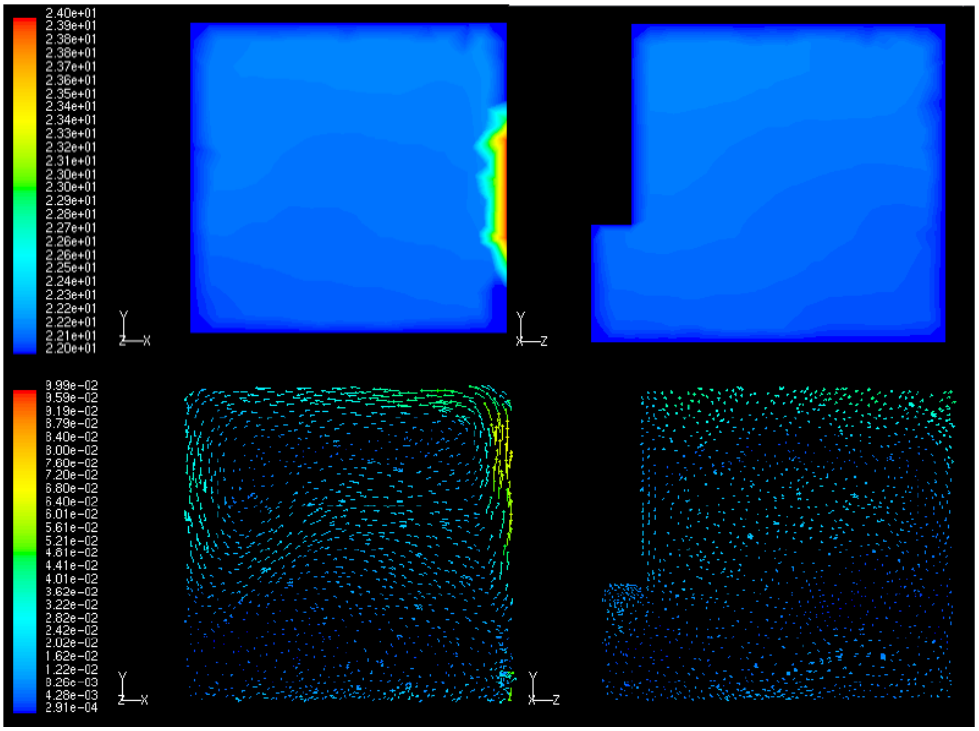


Figure 68 CFD Simulation results of variant 1: the temperature distribution and air velocity distribution in the Sael during the summer. The top figures show the temperature distribution in °C over, respectively, the width and length of the Sael (see figure 8). The lower figures give the air velocity distribution in m/s over, respectively, the width and length of the Sael.

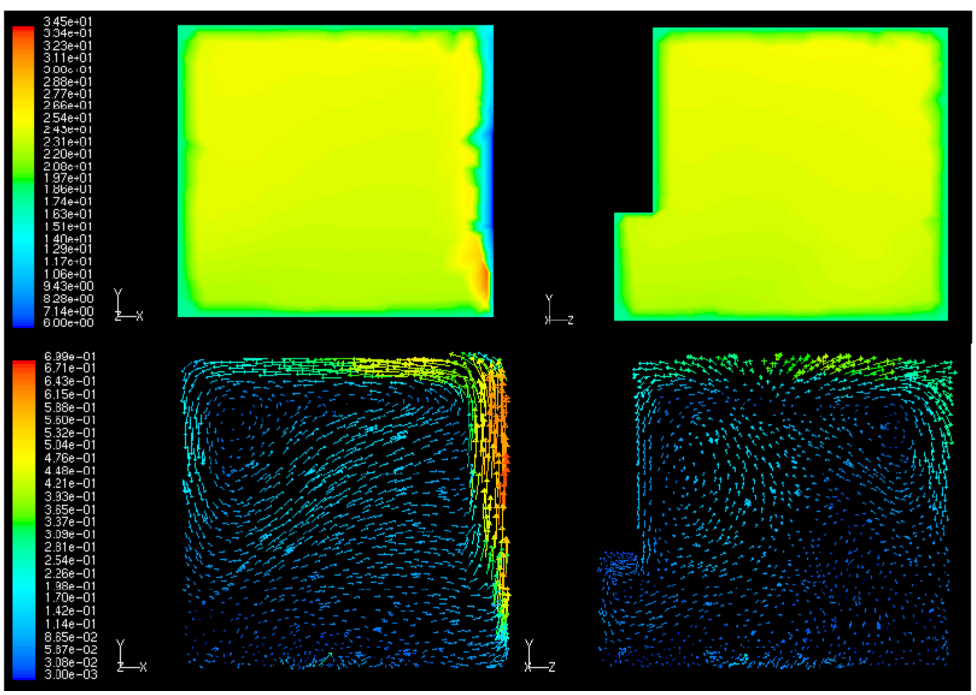


Figure 69 Simulation results of variant 2: the temperature distribution and air velocity distribution over the width and length of the Sael during the winter.

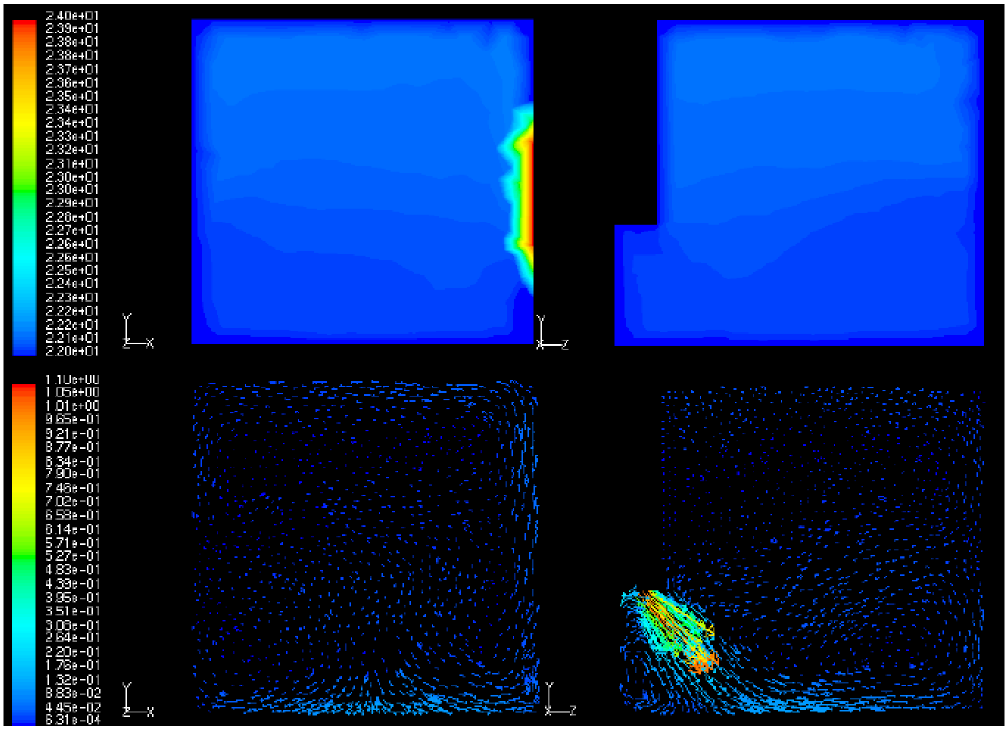


Figure 70 Simulation results of variant 3: the temperature distribution and air velocity distribution over the width of the Sael during the summer, with an intake of 250 m^3/h through the chimney.

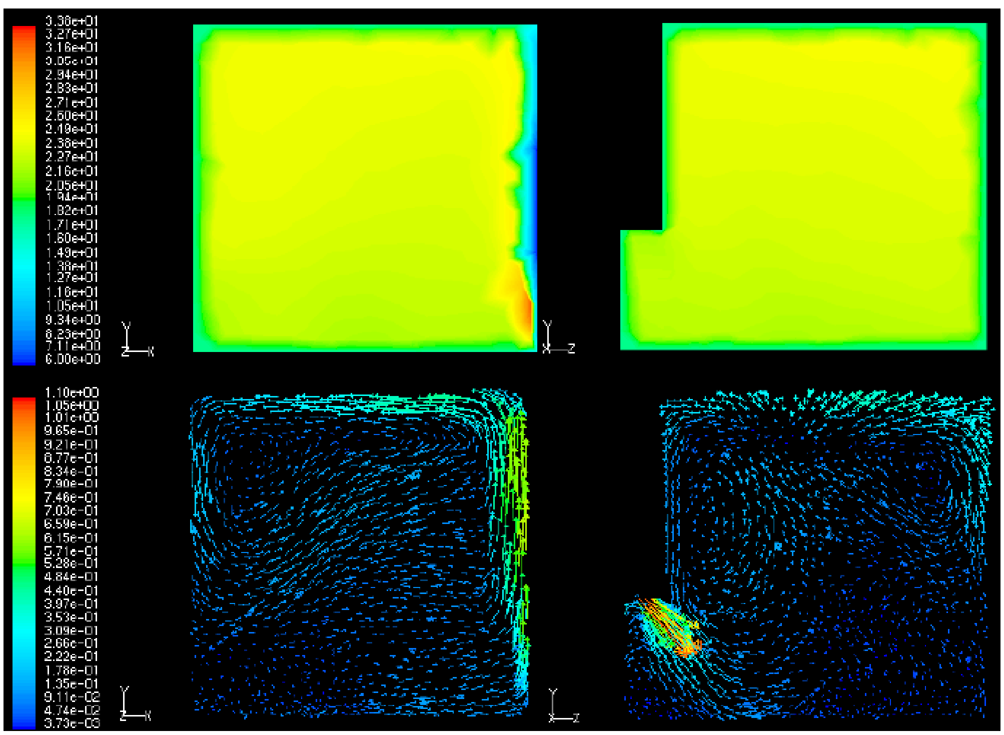


Figure 71 Simulation results of variant 4: the temperature distribution and air velocity distribution over the width of the Sael during the winter, with 250 m^3/h intake through the chimney. The intake temperature is 22 degrees.

APPENDIX G: Results of the CFD analysis for the Church

Figure 72 Simulation results of variant 1: the temperature distribution over the width and length of the Church during the winter.

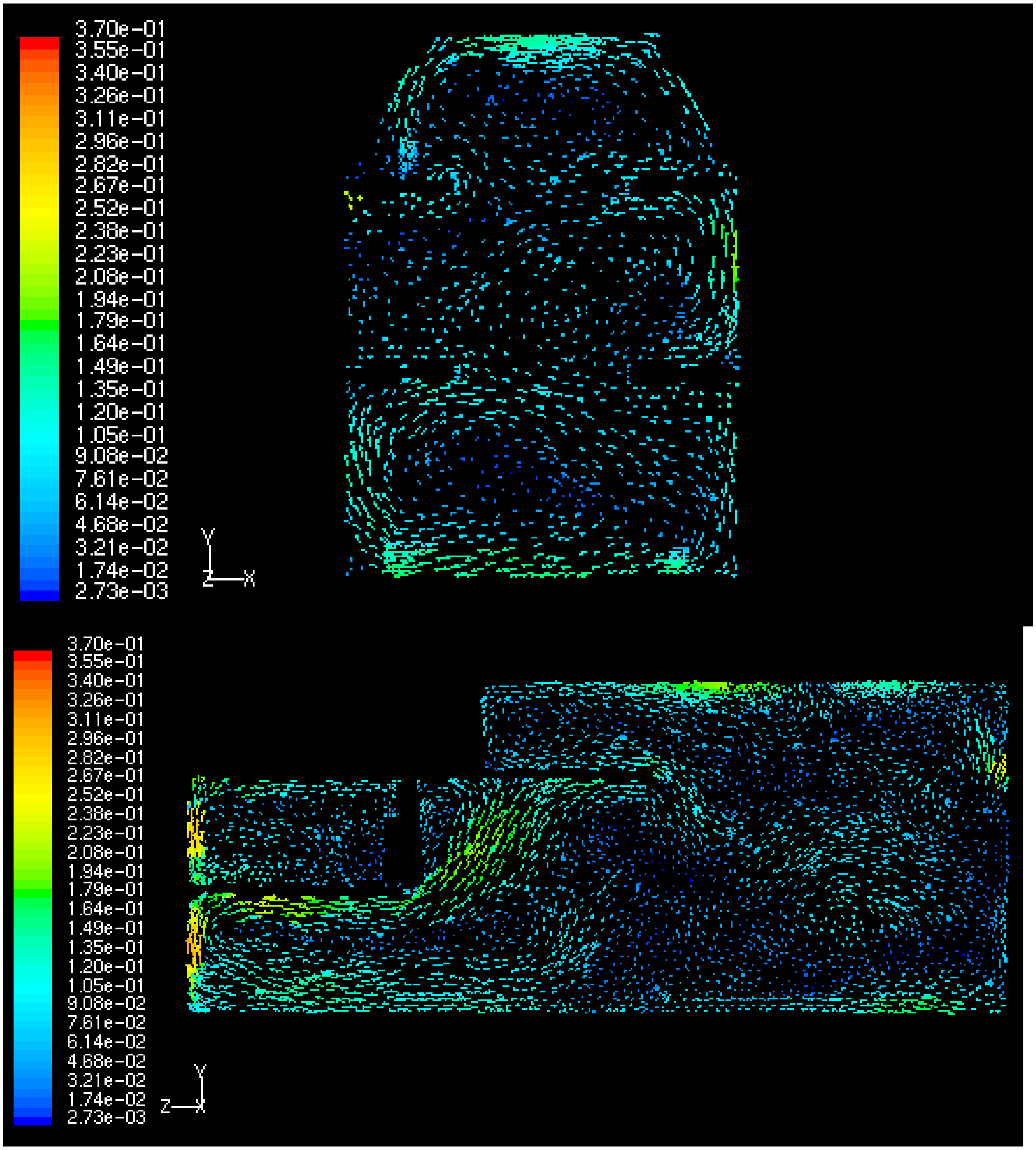


Figure 73 Simulation results of variant 1: the air velocity distribution over the width and length of the Church during the winter.

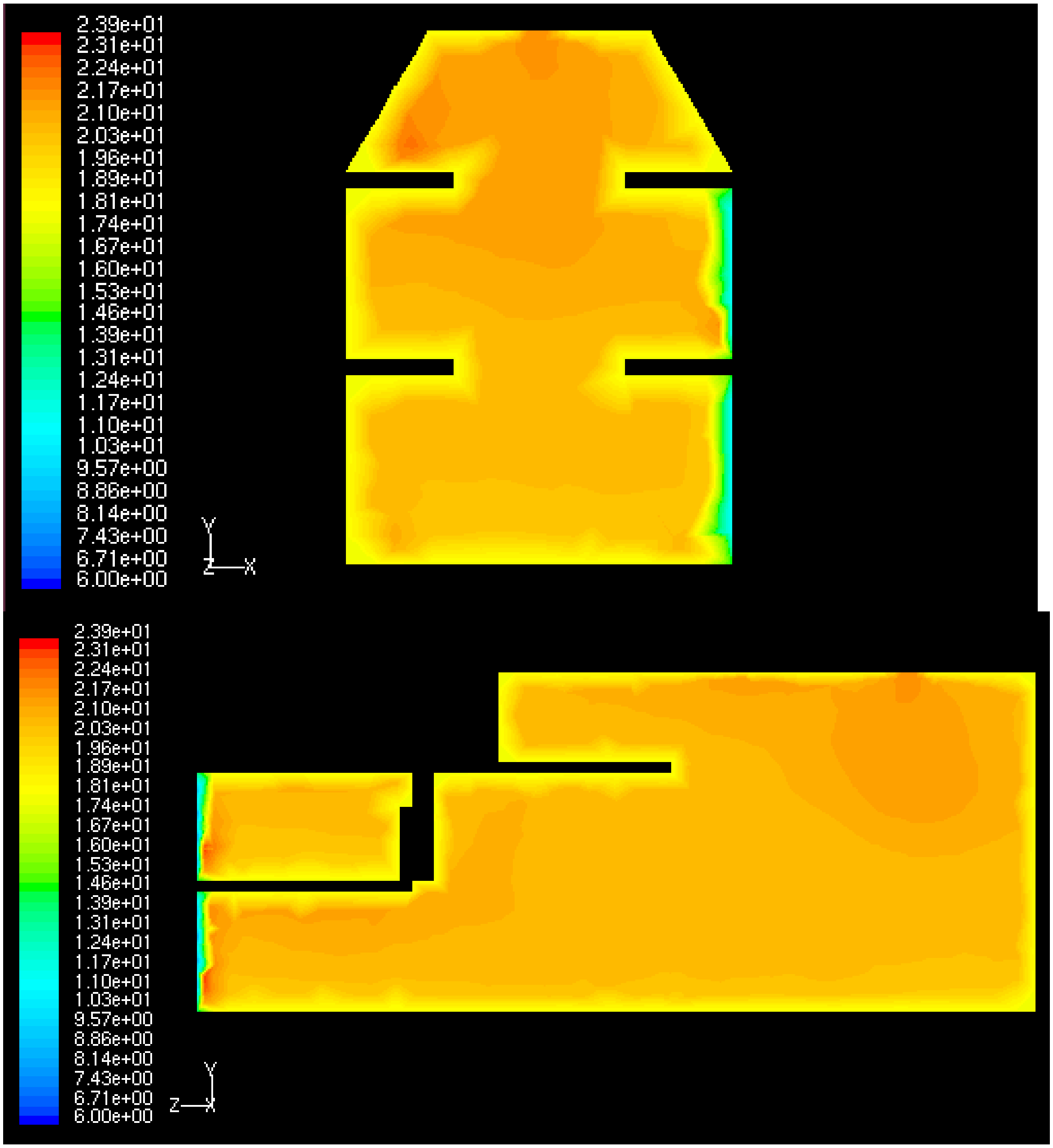


Figure 74 Simulation results of variant 3: the temperature distribution over the width of the Church during the winter, with 250 m^3/h intake through the Lamp of God and 2 times m^3/h through the shaft on the canal side of the Church. The intake temperature is 22 degrees.

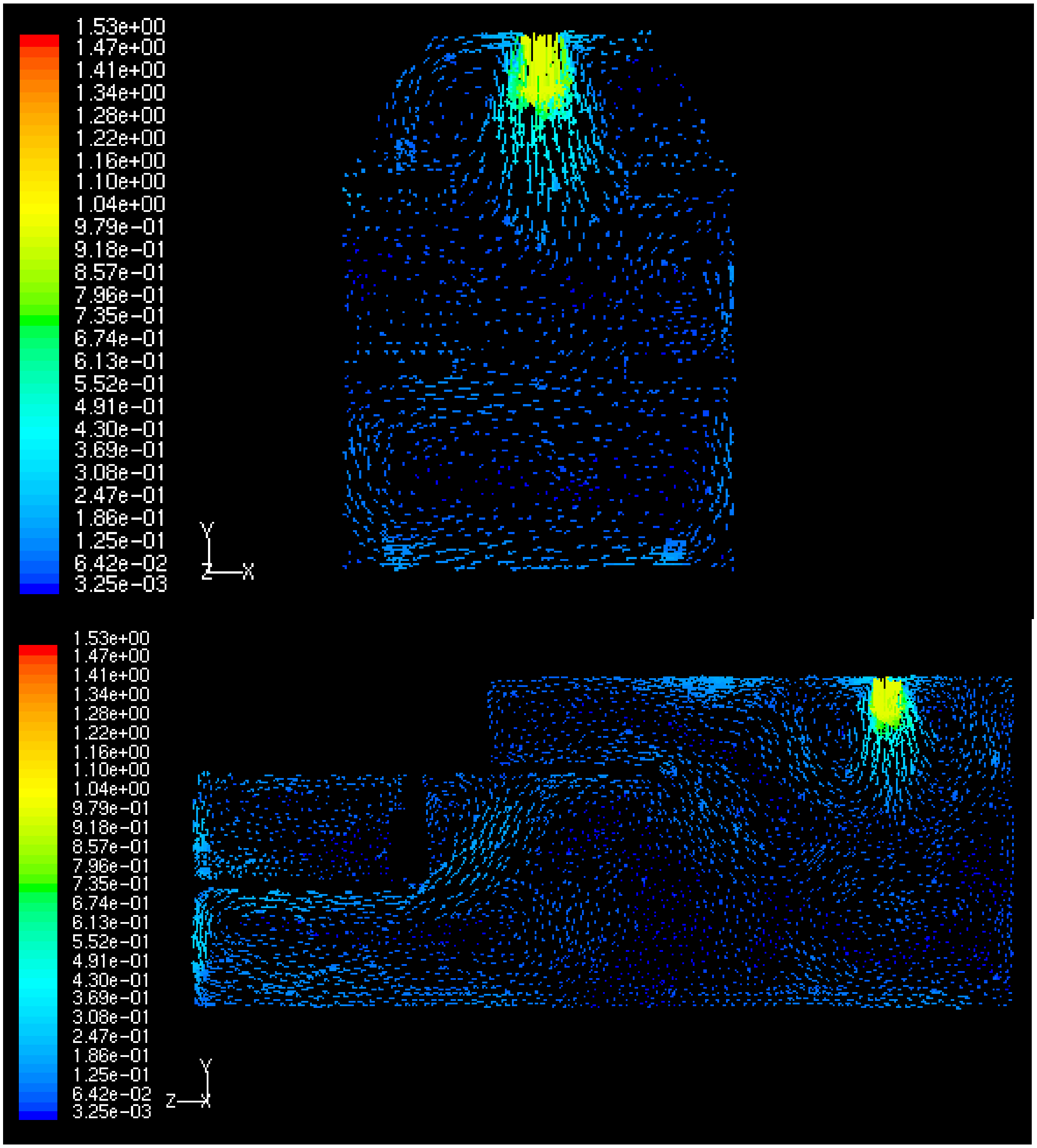


Figure 75 Simulation results of variant 3: the temperature distribution over the width of the Church during the winter, with 250 m^3/h intake through the Lamp of God and 2 times m^3/h through the shaft on the canal side of the Church. The intake temperature is 22 degrees.