TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

MASTERARBEIT

COMPARISON OF CONTAINER CLASSES AND NORMAL CLASSROOMS: A CASE STUDY

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

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Wien, Mai 2013

ACKNOWLEDGEMENTS

The author is greatly indebted to her supervisor Prof. DI Dr. Ardeshir Mahdavi for his valuable guidance and continuous encouragement throughout the duration of this research.

The generous cooperation of TBVG to carry out measurements in the chosen schools is highly appreciated. Particular thanks are due to DI Markus Bartlweber for providing the necessary information.

I would also like to extend my gratitude to the school directors, teachers, and administrative staff for their sincere collaboration. Similarly, the Baden region climate data was crucial in allowing in-depth analysis, and special thanks are due to the ZAMG institute for furnishing it.

This thesis has greatly benefited from the help and information provided by Prof. Dr. Bob Martens and other members of the Department of Building Physics and Building Ecology including Dr. M. Schuss, Dr. R. Zach, and DI. M. Wohlschak.

Among my friends and colleagues, I would like to mention Aida Maleki, Florian Doblhammer and Marco Fiedler for their inspiring insights and help throughout the preparation of this work.

Last, but definitely not least, I would like to express my heartfelt gratitude to my family and especially Mrs Gabrielle Mraz for their caring support during my studies.

CONTENTS

1. INTRODUCTION

1.1. Objective

The major topic of research within this work comprises of climatic differences between container classes and ordinary classrooms. The chosen schools are all located in Lower-Austria, between Baden and Traiskirchen.

A middle and an elementary container-school, together with two normal elementary schools and a normal middle school are selected for comparison. All of the chosen educational spaces are either newly built or have been renovated during the last 9 years.

Temperature and relative humidity variations over a period of five months, and indoor carbon dioxide levels over a period of one month make up the bulk of the experimental data. These factors were chosen for their significant influence on the performance of the pupils and teachers. Prior research (LUKI 2008) shows that a higher than normal concentration of CO_2 can cause loss of concentration in individuals and similar adverse effects on the attention span and general academic performance can be attributed to uncomfortable indoor environments.

1.2. Motivation and Background

The container classes have been in use in some Austrian schools over a period of 20 years, primarily during renovations or new school construction, but also to compensate for the shortage of classrooms, thus changing their role from temporary accommodations to permanent extensions. Since some pupils and teachers are spending the entire academic year in such surrogate classrooms, an examination of indoor environmental factors and energy consumption and cost becomes paramount in justifying their use.

2. LITERATURE REVIEW

In the following section, a short introduction is provided for the indoor environmental conditions in general, and in the classrooms in particular. The factors discussed are thermal comfort and indoor air quality. Further, a number of recent guidelines for obtaining a better learning environment in school buildings are presented.

2.1. Indoor Environmental Conditions

Besides being aesthetically pleasing, the human environment must provide light, air, and thermal comfort. In addition, suitable acoustics and hygiene are essential. Air quality requirements and thermal comfort are addressed in this thesis.

2.2. Thermal Comfort

It has been known for a long time that the thermal comfort of a human being is not exclusively a function of air temperature, but also of five other parameters; mean radiant temperature, relative air velocity, humidity, activity level, and clothing thermal resistance. However, the combined quantitative influence of all the parameters was not appreciated until the "Comfort Equation" established by Prof. P.O. Fanger (Fanger 1973) was introduced. When any combination of these parameters satisfies the equation, the thermal comfort of a majority of individuals can be stated to be neutral (Olesen 1982).

Predicted Mean Vote (PMV) is a well-known example of a thermal comfort performance indicator. Over the last decade, alternative higher resolution indicators employing thermo-physiological models have garnered interest. The adaptive thermal comfort standard (ATC), applying the indoor operative temperature in relation to the outdoor air temperature as the main performance indicator, represents a similarly modern, though a less complex approach (Linden 2008).

2.3. Temperature

Temperature is a measure of the degree of heat intensity. The temperature of a body is an expression of its molecular excitation. The temperature difference between two points indicates a potential for heat to move from the warmer point to the colder point (Bradshaw 2006).

2.4. Humidity

Humidity is the amount of water vapour in a given space. The density of water vapour per unit volume of air is called absolute humidity. It is expressed in units of kilograms (of water) per cubic meter (of dry air). The humidity ratio or specific humidity is the weight of water vapour per unit weight of dry air; it is given in either grams per kilogram or kilogram per kilogram (kg/kg).

The amount of moisture that air can hold is a function of temperature. The warmer the air, the more moisture it can hold. The amount of water present in the air relative to the maximum amount which it can hold at a given temperature without causing condensation (water present ÷ maximum water holding capability) is known as the degree of saturation. This ratio multiplied by 100 is the percentage humidity.

A low humidity percentage indicates relative dryness, and high percentages indicate high moisture. Percentage humidity is often mistaken with relative humidity (RH), which is the ratio of the actual vapour pressure of the air-vapour mixture to the pressure of saturated water vapour at the same dry-bulb temperature times 100 (Bradshaw 2006).

The humidity in indoor air may directly or indirectly have an impact on the occupants. High air humidity, condensation or ingress of moisture stimulates the growth of moulds and other fungi etc. and causes allergies and malodours. Increased humidity may also augment the emission of chemicals like formaldehydes from construction materials (Anderson et al. 1976). Low humidity, on the other hand, may cause a sensation of dryness and irritation of skin and mucous membranes for some occupants (Reinikainen 1990). Normally few problems occur when the relative humidity is between 30 and 70%, assuming that no condensation takes place (BS5250)(X. IEA Annex 1990).

One can calculate the absolute humidity (AH) from the relative humidity (r) using three equations:

(1) The equation for mixing ratio,

(2) An equation for relative humidity expressed in terms of mixing ratio,

(3) The Clausius-Clapeyron equation, which relates saturation vapour pressure to temperature.

The result of combining the three equations is as follows:

$$AH = \left(\frac{1324 \times r}{T}\right) \times [exp\{5417.75 \times \left(\frac{1}{273} - \frac{1}{T}\right)\}]$$

Where AH (absolute humidity) is expressed in grams per cubic meter, T is temperature in Kelvin, r is relative humidity (range is 0 to 1), and the relation holds true for T>273 °K. For T<273 °K, replace 5417.75 with 6139.81 (Biancomano und Shulman 1990).

2.5. Indoor Air Quality (CO_2 Concentration)

There are two basic requirements that must be met by the air quality in an enclosed and occupied space: First, the health risk associated with breathing the air should be negligible. Secondly, the air should be perceived as fresh and pleasant rather than stale, stuffy and irritating (ECA 1992).

Humans produce carbon dioxide CO_2 in proportion to their metabolic rate. Carbon dioxide, by quantity it is the most important human bioeffluent. At the low concentrations typically occurring indoors CO_2 is harmless and it is not perceived by humans. Still it is a good indicator of the concentration of other human bioeffluents being perceived as a nuisance. As an indicator of human bioeffluents, CO_2 has been applied quite successfully for more than a century (Pettenkofer 1858).

Figure 1 shows the percentage of the dissatisfied visitors as a function of the CO_2 concentration (above outdoors) for spaces where sedentary occupants are the exclusive pollution sources. In lecture theatres, assembly halls and similar rooms with a high and variable occupancy rate, CO_2 -monitoring is a well-established practice for controlling the supply of outdoor air (X. IEA Annex 1990).

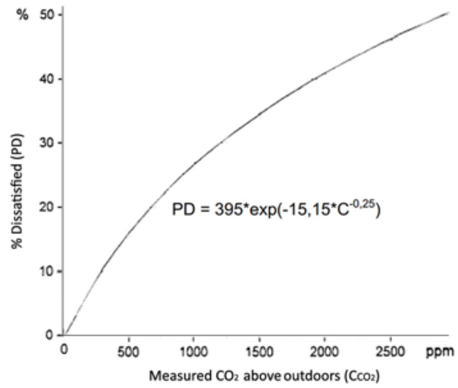

Figure 1: Carbon dioxide as an indicator of human bioeffluents. The curve shows the perceived air quality (% dissatisfied) as a function of the carbon dioxide concentration. It applies to spaces where sedentary occupants are the exclusive pollution sources. The concentration of carbon dioxide outdoors is typically around 350 ppm

According to ÖISS (ÖISS 2012), section 4. Building Physics indoor environment, and energy efficiency, the CO_2 concentration of classrooms should not exceed 1500 ppm. Studied examples show that the Pettenkofer aspired value of 1000 ppm is hard to achieve even in school buildings with mechanical ventilation systems and the consequences of attempting to reach these lower concentrations would have a negative impact on the perception of indoor comfort of the users (drafts and high energy consumption).The American scientists Rudnick and Milton in 2003 studied, the risk of influenza transmission based on CO_2 concentrations in classrooms. In his experiment, thirty individuals were placed in a classroom for duration of four hours, where one individual had acute influenza. The results show that with a 1000 ppm CO_2 concentration five people contracted the illness. At 2000 ppm the number rose to twelve and at 3000 ppm fifteen individuals became ill(Rudnick und Milton 2003).

2.6. Norms for Indoor Conditions in Austrian Schools

New OIB guidelines have been established for mobile classes in the recent years. The school containers which are predate 2009, can be kept as they are, however, newly installed containers must comply with the OIB guidelines. These guidelines state that if possible, the heating system has to be connected to the heating system of the school.

The OIB guidelines imply also the Austrian norms (Ö-Norm). At present (2013), to our knowledge no research has been performed in Austria on the container schools and their indoor air quality or thermal comfort. Some general qualities for classrooms are listed in the following:

1. In winter, **air temperatures** should lie between 20 and 22 °C. According to ÖISS (ÖISS 2012) the needed apparent air temperature of classrooms and multipurpose rooms in schools has to be at least 20 °C. Whereas this temperature is calculated as the mean value of air temperature and temperature of the surrounding surfaces (ÖNORM H 6000-3, 1989). In the ÖNORM (ÖNORM EN 7730, 2006) a table suggests three categories A-C for classrooms separated in winter and summer time defining the optimum operative temperature. The suggested operative temperatures in the particular categories are shown in Table 1:

Table 1: Example design criteria for spaces in schools

	Category	Summer (Cooling season)	Winter (Heating season)
Classroom, Conference room, Auditorium ±	A	24,5 ± 1,0	22,0 ± 1,0
	B	24,5 ± 1,5	22,0 ± 2,0
	C	**24,5 ± 2,5**	**22,0 ± 3,0**

Table 2: Categories of thermal environment in ISO_7730

	Thermal state of the body as a whole		Local discomfort			
Category	PPD%	PMV	DR%	PD% Vertical air temperature difference	PD% Caused by warm or cool floor	PD% Radiant asymmetry
A	<6	-0.2<PMV<+0.2	<10	<3	<10	<5
B	<10	-0.5<PMV<+0.5	<20	<5	<10	<5
C	<15	-0.7<PMV<+0.7	<30	<10	<15	<10

The categories A-C correspond to different expectation as follows:

A: High level of expectations; recommended for rooms with very sensitive and vulnerable occupants

B: Normal level of expectations, recommended for new and renovated buildings
C: Acceptable, moderate level of expectations, existing buildings (case of this research)

In summer and particularly in the humid days, the temperature should be 3-6 °C less than the maximum outside temperature (ÖISS 2012).

2. The **relative humidity** should be between 40 and 50%. Humidity below 30% leads to dehydration in the airways. For an adequate sense of well-being and avoidance of damage are in ÖISS section 4. Building Physics indoor environment and energy efficiency, specific humidity values defined. At 20°C ambient air temperature the relative air humidity, in an enclosed space during the heating period, in the long term, should not exceed the specified limit of 25% to 60% (ÖISS 2012) (ÖNORM EN 15251, 2007).

According to *Komfortlüftung* and ÖISS (ÖISS 2012) the aspiring range is 30 to 45% RH. It must be ensured that, also in very cold outside temperatures, the indoor Humidity does not fall below 20%. From 0 ° C to -10 ° C outside temperature, is the RH allowed to fall 1% per 1°C.

Usually the air does not need to be humidified. The humidity has little effect on the temperature perception and the perception of indoor air quality with sedentary activities. Prolonged high ambient humidity causes microbial growth, while very low humidity (<15% to 20%) causes dryness and irritation of the eyes and respiratory tract.

For the case when humidification and dehumidification are utilized, the set values are recommended by ÖNORM (ÖNORM EN 15251, 2007) as shown in Table 3. Moreover in the ÖNORM an absolute humidity of 12 g/kg (14 g/m³) is suggested (ÖNORM EN 15251, 2007).

Table 3: Example of recommended design criteria for the humidity in occupied area for installation of humidifying and dehumidifying facility in ÖNORM EN 15251 (2007.09.01)

	Category	Set value for dehumidification	Set value for humidification
Rooms where the humidity criteria are determined by the occupation.	A	50	30
	B	60	25
	C	70	20

3. The average **temperature of the surrounding surfaces** should be of the same level as the air temperature. Deviations of more than 2 ° C should be avoided(ÖISS 2012).

According to ÖNORM (ÖNORM EN ISO 7730, 2006) the following additional room climate recommendations apply in relation to surface temperatures in rooms with people who perform a light sedentary work:

- The temperature difference between the two wall surfaces should not exceed 10 °K.

- The temperature difference between the floor surface and ceiling surface should not exceed 5 °K.

- The floor temperature should be between 19 °C and 26 °C (a maximum of 29 °C for under- floor heating).

4. The classrooms should be such that a sufficient **air volume** is available per pupil. In a secondary school per pupil a volume of 8 m^3 (for elementary schools 6 m^3) is proposed. With this dimensioning, a fourfold air change per hour, would ensure a fresh air supply of 30 m^3 per person per hour, which could be achieved with a cross ventilation.

In ÖISS(ÖISS 2012) and *Komfortlüftung* homepage, the minimum air volumes per pupil for the Interpretation (resulting from the max. CO_2 requirement) is defined as follows:

Table 4: minimum needed air volume per pupil depending on age

Age	for about 1200 [ppm]	for target about 1000 [ppm]	
6-10	19 [m^3 / h]	25 [m^3 / h]	(i.e. elementary school)
10-14	23 [m^3 / h]	30 [m^3 / h]	(i.e. secondary school)

5. **Indoor air quality** according to ÖNORM (ÖNORM EN 13779, 2008) is given as following;

IDA 1: high indoor air quality <350 over AUL

IDA 2: Moderate air quality + 400-600 (Default 500) ppm over AUL

IDA 3: moderate air quality + 600-1000 (Default 800) ppm over AUL

IDA 4: low indoor air quality> 1,000 over AUL

Table 5: Defined outside air CO_2 values in ÖNORM EN 13779 (AUL)

	AUL value [ppm]
Country	350
City	400
City centres	450

3. METHODOLOGY

3.1. Selection of the Objects

The selected schools were located about 20 km south of Vienna in lower Austria, in Traiskirchen, Tribuswinkel and Baden. These were all in walking distance of Badenerbahn train line going from Vienna to Baden.

These are all towns in the district of Baden with a sea level between 200 – 230 m ü. A.

Figure 2: Area of the selected sites

3.1.1. **Site description**

The schools marked with blue circles in Figure 3, are the container schools and red spots symbolize standard schools. The largest distance between the schools is about 3.7 kilometres, so it can be assumed that these schools have all identical outdoor conditions.

Figure 3: Position of the selected schools (red: normal, blue: container schools)

3.1.2. **Selected objects**

Measurements were being made by sensors which were situated in different positions in each classroom of the chosen schools. The goal was to position all the sensors at similar heights and out of strong air currents and sunlight.

As shown in Figure 3, we studied five schools, two of which two (marked in blue) are the selected container schools. All of these have been renovated since 2004 and in a good condition.

From all schools four classrooms were selected and two or three sensors were installed in each. The schools and the corresponding installed sensors are listed in Table 6. The U-Values of the each school’s envelope are assembled and shown in Table 7 .

The measuring time of the WÖHLERs was throughout June with an exception of S3, which was additionally measured during April and May (14.04.2011-20.05.2011) and the HOBOs were measured for 5 months during February to July 2011.

Table 6: list of the schools and the corresponding installed sensors

	classes	HOBOs		WÖHLERs
Primary school Traiskirchen (S1)	101	201	301	
	102	202	302	W9
	103	203	303	W8
	104	204		
Primary school Tribuswinkel (S2)	201	205	305	
	202	206	306	W5
	203	207	307	W4
	204	208		
Primary school Baden (Container) (S3)	301	209	309	W1
	302	210	310	W2
	303	211	311	W3
	304	212		
secondary school Traiskirchen (main building) (S4)	401	213	313	W7
	402	214	314	W6
	403	215	315	
	404	216		
secondary school Traiskirchen (Container) (S5)	501	217	317	W12
	502	218	318	W10
	503	219	319	
	504	220		W11

Table 7: U-Values [$W.m^2.K^{-1}$] of the main elements of the schools

	U-Value ext. wall	U-Value window	U-Value ext. door	U-Value roof
Primary school Traiskirchen[1]	0.40	1.80	1.80	0.22
Primary school Tribuswinkel[2]	0.20	1.30	1.80	0.15
Primary school Baden[3]	0.37	1.10	1.10	0.37
secondary school Traiskirchen[4]	0.35	1.70	1.70	0.20
secondary school Traiskirchen[3]	0.37	1.10	1.10	0.37

1 minimum requirements of the building envelope in NÖ for the restoration in 2002 (default values from OIB guideline 6 from 03.1996)
2 received data from TBVG (U-Value of the ceiling to attic = 0.22 [$W.m^2.K^{-1}$])
3 calculated values
4 minimum requirements of the building envelope in NÖ for the restoration in 2009 (OIB guideline 6)

3.1.2.1. Volksschule Traiskirchen (S1)

During the summer holidays of the school-year 2002/03, the exterior of the building was renovated (insulated) and redesigned. In the school year 2003/04, the class rooms were extensively remodelled to bring the school to a more modern standard. At the start of school year 2004/2005 the renovations were completed. Most of the classes were south-east and some were north-west oriented. Around 22 pupils in the age of 6 to 9 years were studying in each classroom. The chosen classes had a size of 63-64 m² with an approximate height of 3.5 m. This means an air volume of approx. 9.5 m³ per pupil was available. During the winter season the heating system of the school had been set to a day temperature (Mo.-Fr. 05:00-13:00) of 22°C and a night temperature of 18°C.

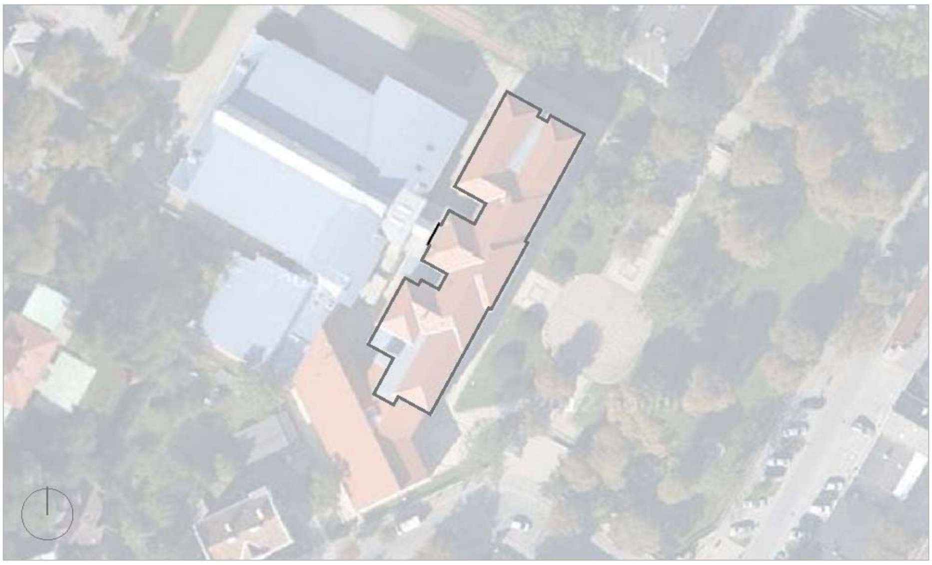

Figure 4: Site plan Volksschule Traiskirchen

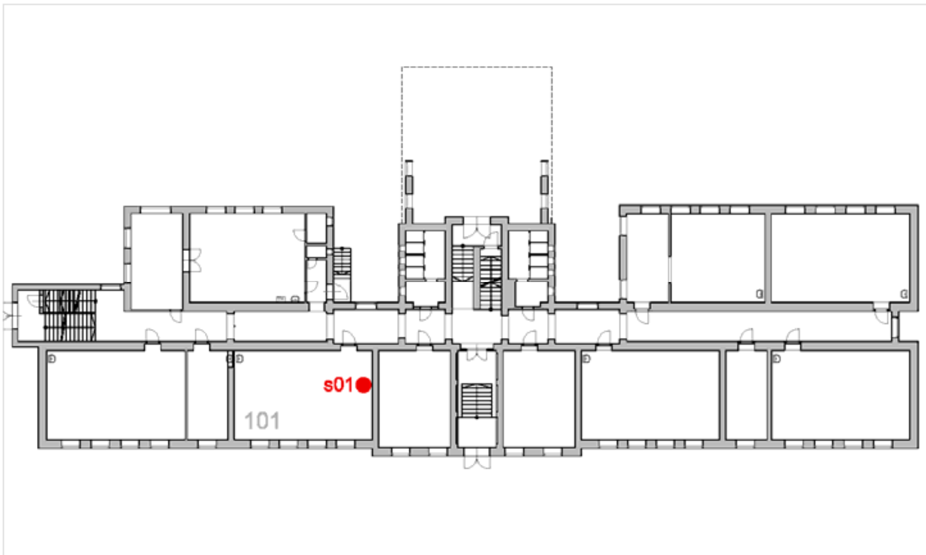

Figure 5: Ground floor of the Volksschule Traiskirchen, s stands for sensor and 01 are the last two digits of the Hobos used for measurement as in Table 6

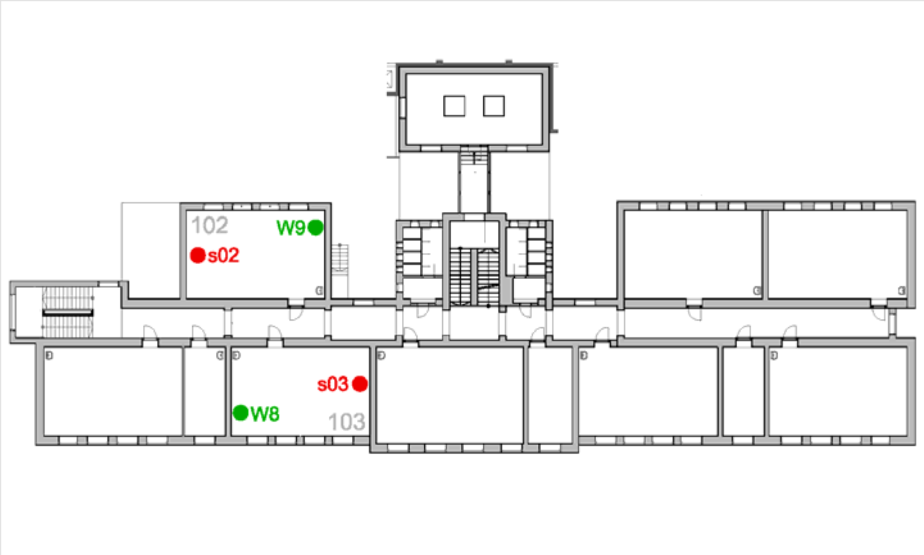

Figure 6: First floor of the Volksschule Traiskirchen

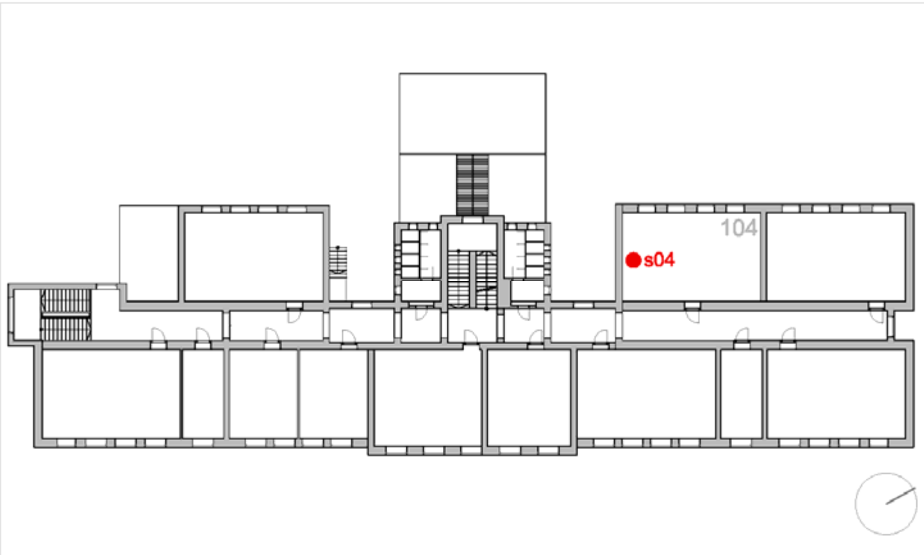

Figure 7: Second floor of the Volksschule Traiskirchen

In each floor and on each side (north-west, south-east) one to two classes were chosen and some HOBO sensors were installed. Two of the classrooms in the 1st floor also got WÖHLER sensors to measure the CO_2 values. The HOBO sensors were all installed on top of the cupboards at the back of the classes in the same height (approx. 2m). Later on for the CO_2 measurements, the WÖHLER sensors were also added on top of the cupboards in the front of the classrooms next to the teacher's desks. Since only twelve WÖHLERS were available, in each school only two sensors were installed (exceptions were S3 and S5 with 3 sensors each). As it can be seen from Figure 6, these were classroom Nos.102 and 103 both lying in the first floor but facing different directions. To illustrate the places where exactly the sensors were installed, two pictures are added as shown in (Figure 8).The HOBOs are marked in red colour and the WÖHLERs with a green solid circle, as shown in the plans.

Figure 8: Sensor location in S1

3.1.2.2. Volksschule Tribuswinkel (S2)

The main school building was built in 1970 at Lichteneckergasse. In June 2004 after one year the refurbished elementary school building including additional constructed media, IT and business space and the renovated gym were formally handed over. Six years later the annex of five classes and an exercise room of the elementary school Tribuswinkel were finished in March 2010. The classes are south, south-west oriented. Around 22 pupils with the age of six to nine years are studying in each classroom. The chosen classes had a size of 60-61 m², an approx. Height of 3.1 meters and 8.2 m³ of available air volume per pupil.

During the winter season the heating system of the school has been set to a day temperature (Mo.-Fr. 05:00-13:00) of 22 °C and a night temperature of 18°C.

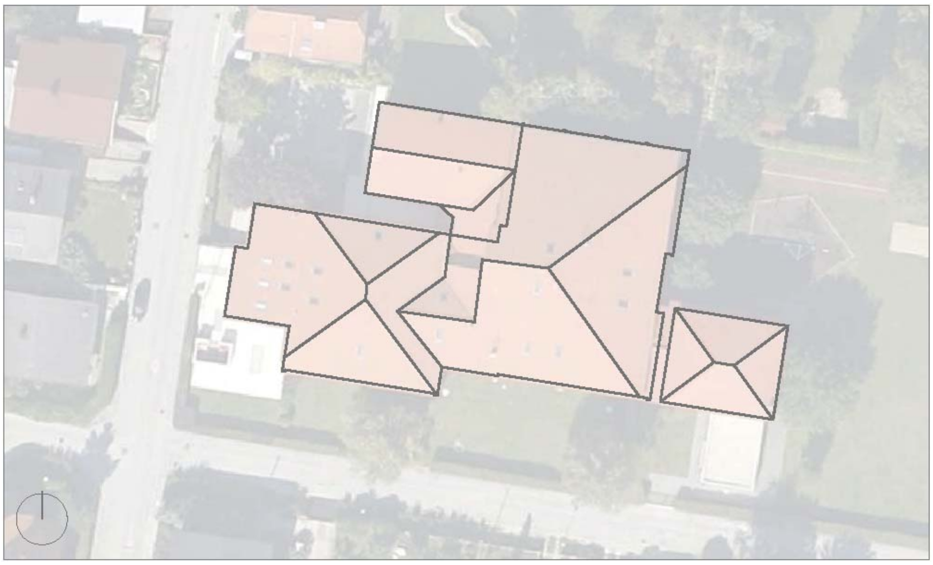

Figure 9: Site plan Volksschule Tribuswinkel

In each floor, two classes were chosen and the HOBO sensors were installed. Two of the classrooms in each floor also obtained WÖHLER sensors to measure the CO_2 values.

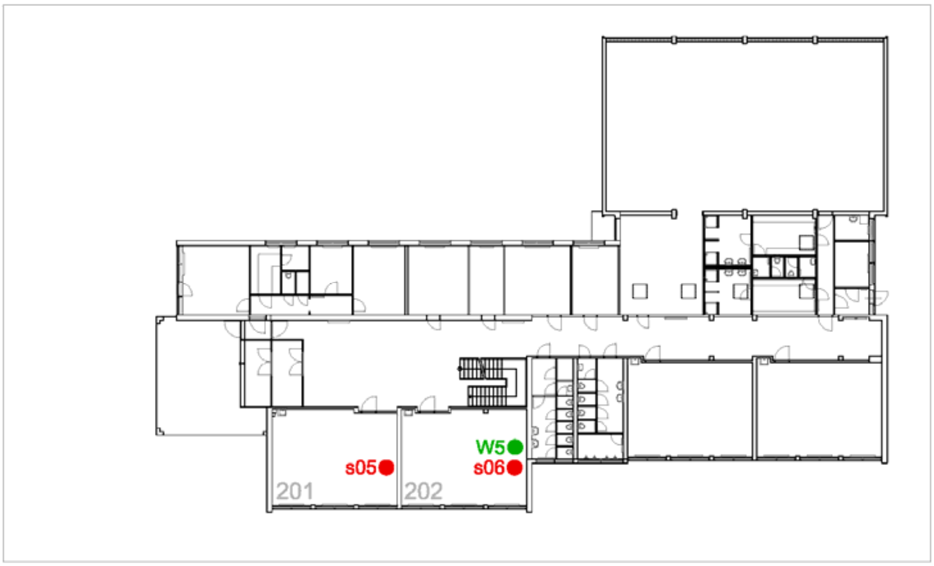

Figure 10: Ground floor of the Volksschule Tribuswinkel

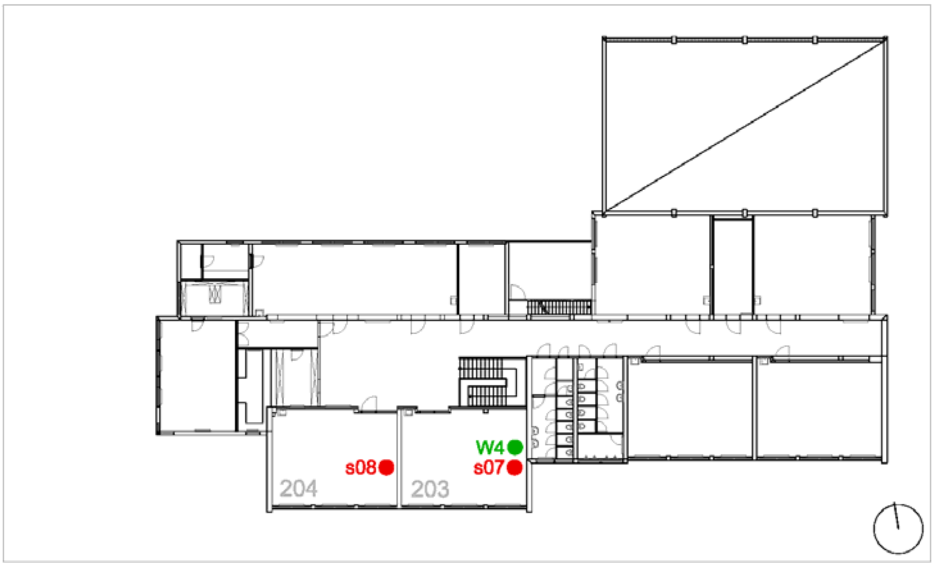

Figure 11: First Floor of the Volksschule Tribuswinkel

In this school, the HOBO sensors were installed at the sides of the cupboards standing at the back of the classes all in the same height (approx. 1.8m). Later on for the CO_2 measurements were the WÖHLER sensors also added on top of the cupboards near the HOBOs in two of the classrooms. As it can be seen in Figure 10 and Figure 11, these were classrooms Nos.203 and 202, one in each floor of the school. Two pictures showing these are as illustrated in Figure 12. The HOBOs are marked with red colour and the WÖHLERs with a green solid circle, as before.

Figure 12: Location of the sensors in S2

3.1.2.3. Container school Volksschule Baden (S3)

In 2010 the refurbishment of the main school building of “VS Pfarrplatz Baden” started. For the two years a container school was build up in Flamminggasse 28-30 in Baden. The classes were north-west, south-east oriented. As shown in the Figure 13 to Figure 15 the main part of the building (north arranged part) contains altogether 20 (positioned above one another) classrooms, each class being made of four containers set together on the length side. Up to 22 pupils with the age of six to nine years studied per classroom. The classes had a size of 60-61 m², were approx. 2.25 m high and had an air volume of approx. 5.9 m³.

The container school had an electric-heating which was regulated by the occupants.

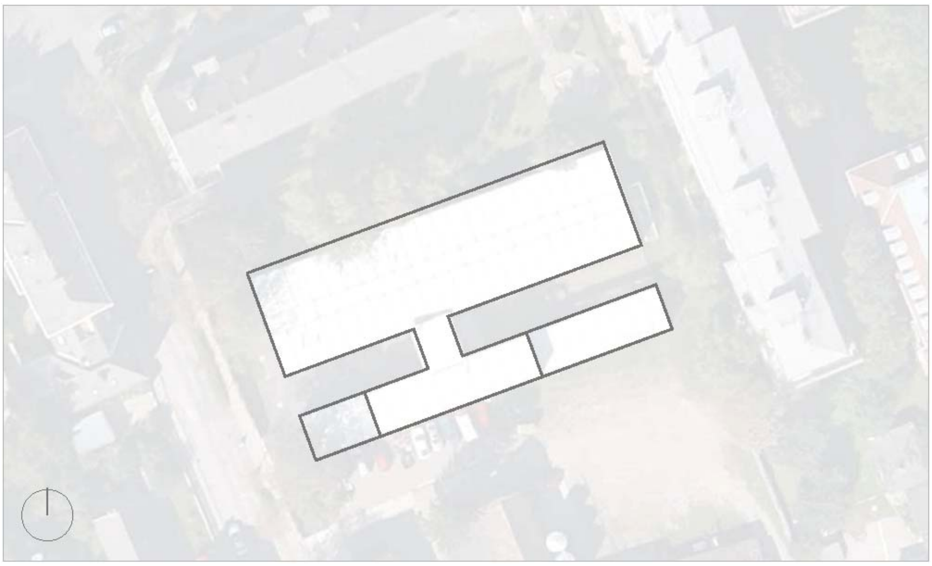

Figure 13: Site plan Volksschule Baden

In the ground floor three classes and in the first floor one classroom was chosen and HOBO sensors were installed. All three classes of the ground floor received WÖHLER sensors to measure the CO_2 values.

Figure 14: Ground floor of the Volksschule Baden

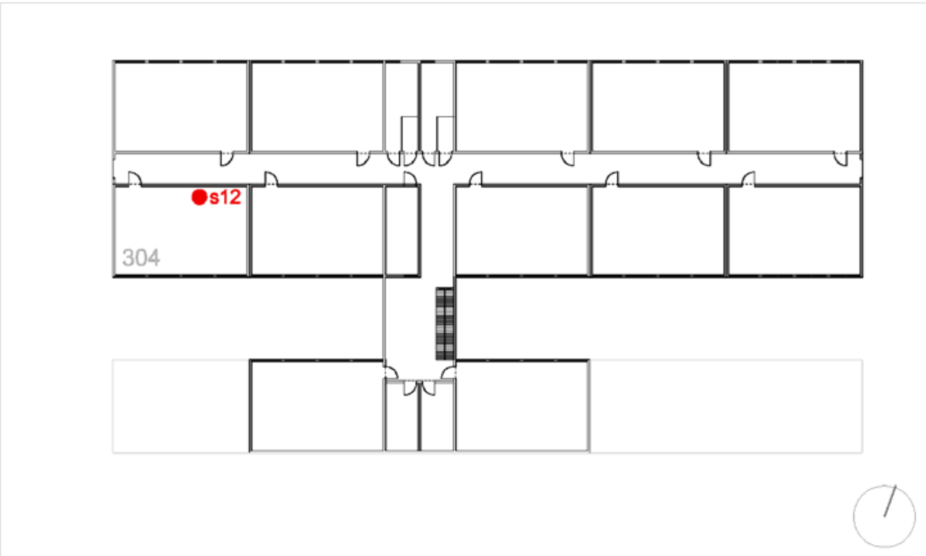

Figure 15: First floor of the Volksschule Baden

In this school, the HOBO sensors were installed at the sides of the cupboards all in the same height (approx. 1.8m). The shelves were positioned on the inside wall of the classrooms. Later on, for the measurements of CO_2, the WÖHLER sensors were also added directly on the inside wall of the classrooms near the HOBOs in three of the classrooms. These classrooms (Nos. 301-303) were all in the ground floor, as shown in Figure 14. Again two pictures show this in Figure 16.

Figure 16: Location of the Sensors in S3

3.1.2.4. Hauptschule Traiskirchen (main building) (S4)

The general renovation of the school (built in 1970) was carried out during 2009 to 2011. In September 2011, the renovation of the sports and computer science secondary school Traiskirchen was completed. Around 22 pupils with the age of ten to fourteen years pupils were studying in each classroom. The classes are north-east, south-west oriented. The chosen classes were 72-73 m² large. These have a height of approx. 2.5 m and ca. 8 m³ air volume per pupil.

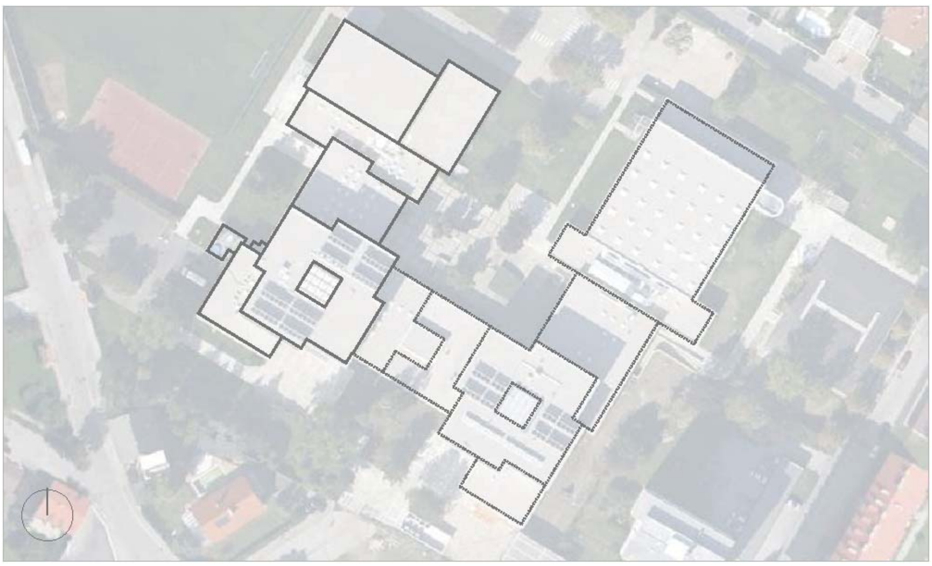

Figure 17: Ground floor of the Hauptschule Traisirchen

In the first floor and second floor, two classes were selected and the HOBO sensors were positioned. In both classes of the first floor, the WÖHLER sensors were installed to measure the CO_2 values.

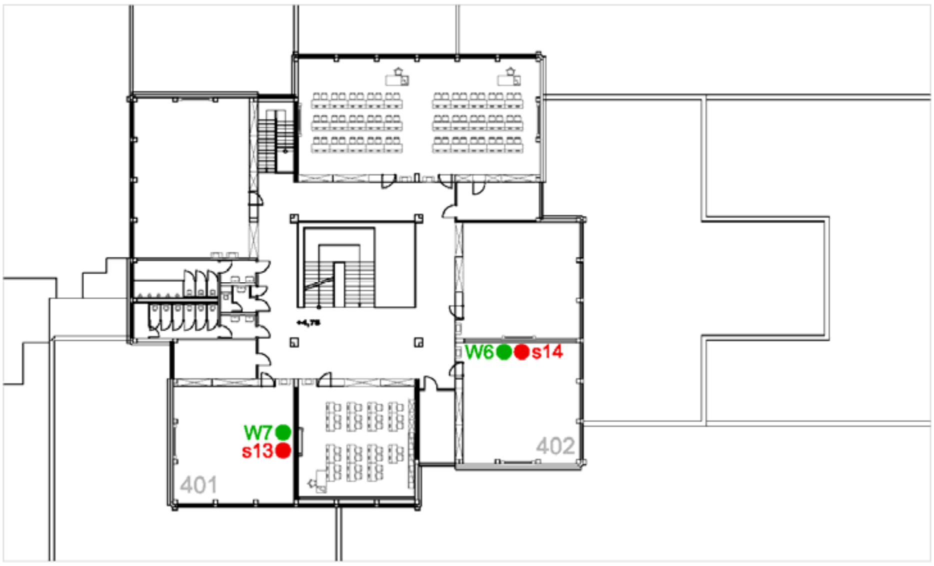

Figure 18: First Floor of the Hauptschule Traisirchen

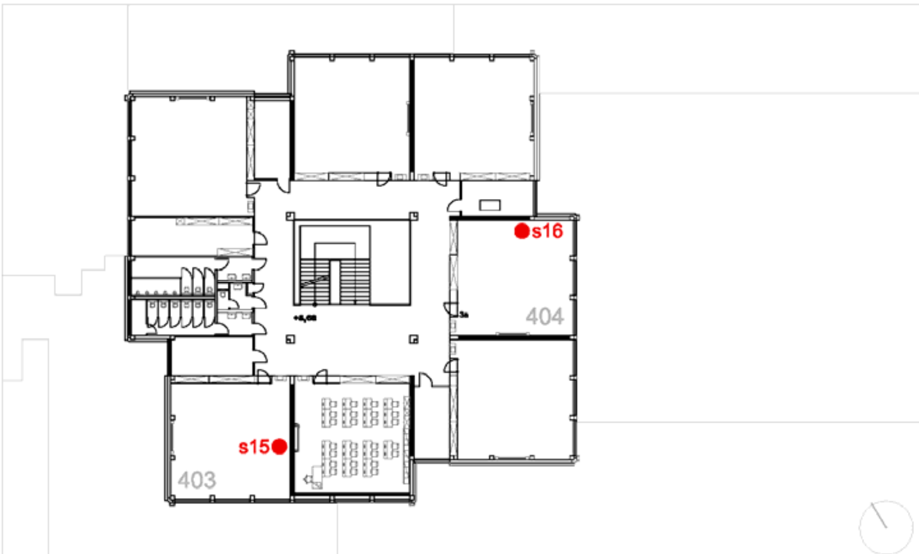

Figure 19: Second floor of the Hauptschule Traisirchen

In this school, the HOBO sensors were positioned at the side of the cupboards all at the same height (approx. 1.8m). These were at the back of the classrooms. Later on for the measurements of CO_2, the WÖHLER sensors were also added on the top of the cupboards near the HOBOs in two of the classrooms. As it can be seen from Figure 14, these were classrooms Nos. 401 and 402, both on the first floor. Again two pictures show these as illustrated in Figure 20.


Figure 20: Location of the sensors in S4

3.1.2.5. Hauptschule Traiskirchen (Container) (S5)

For the general renovation during 2009 to 2011 of the school some container classes (built in year 2004) were positioned in the front schoolyard. Around 21 pupils between ages ten and fourteen were studying in each classroom.

The classes were east-west oriented. The classes were made of four containers set together in the length direction and had an area of 60-61 m², a height of approx. 2.25 m, and an air volume of about 5.9 m³. The container school had an electric-heating which was regulated by the occupants.

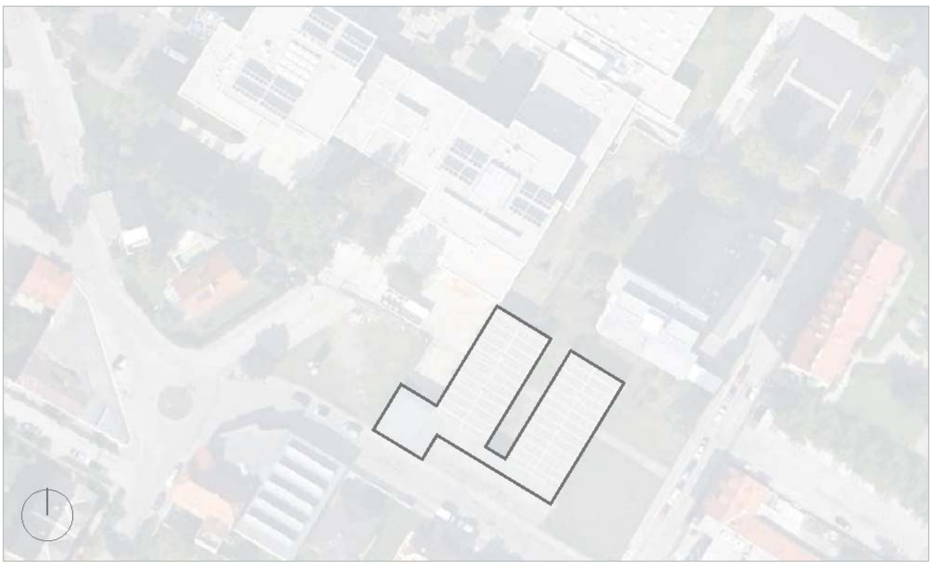

Figure 21: Site plan Hauptschule Traisirchen (Container)

In the one storey building all the HOBO sensors were installed in the west part of the temporary construction. Three classes got WÖHLER sensors for measuring the CO_2 values.

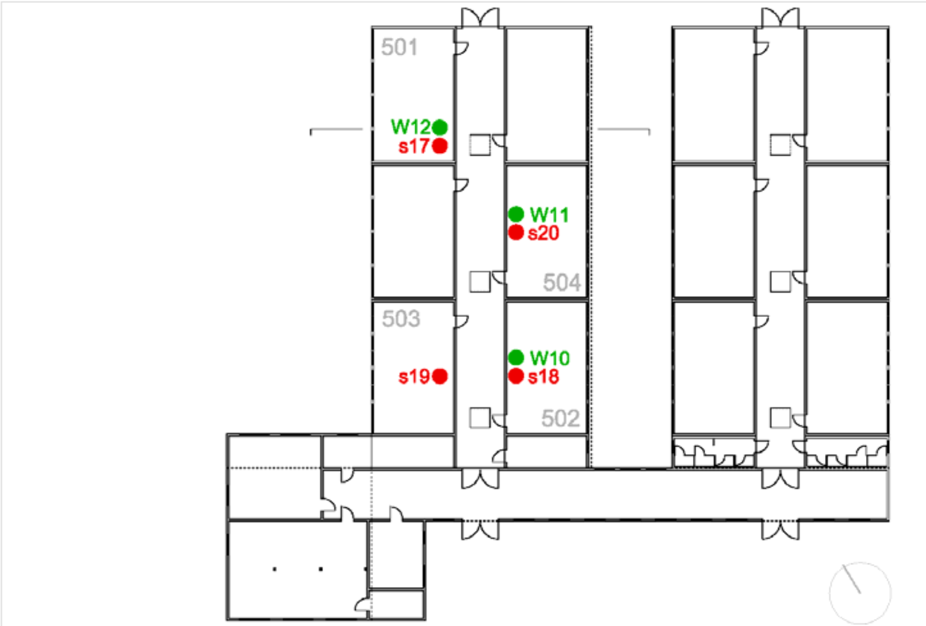

Figure 22: Ground floor of the Hauptschule Traisirchen (Container)

In this school the HOBO sensors were installed at the sides of the inner wall of the classes (height: about 1.5m). Later on for the CO_2 measurements the WÖHLER sensors were also added directly on the inside wall of the classrooms near the HOBOs in three of the classrooms. As shown in Figure 22 these were classroom No.501 facing west and 502 and 504 facing east. Again two pictures showing this are provided in Figure 20.

Figure 23: Sensor location in S5

3.2. Heating Data

Heating degree day (HDD) is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDD at that location.

Heating degree days are defined relative to a base temperature; the outside temperature above which a building needs no heating. The most appropriate base temperature for any particular building depends on the temperature that the building is heated to in this case 20°C (Internal gains increase this temperature by about 1 to 2°C).

HDD $_{20/12}$ are a measure of how much (in degrees), and for how long (in days) of a specific month, outside air temperature was lower than a base temperature of 20°C the daily outside mean temperature is below 12°C. In other words:

$HDD_{20/12} = \sum (20 - t_{em})$

In Table 8 the HDD $_{20/12}$ in Baden during the measurement time is listed.

Table 8: HDD $_{20/12}$ in Baden

January	583,70
February	516,90
March	364,40
April	74,40
May	39,50
June	0,00

3.3. Measurements

To determine the thermal comfort and air quality levels of the schools chosen, data logger devices that measure temperature, humidity and CO_2 were installed in the classrooms. The measurements of temperature and humidity were made from February till the end of June and the CO_2 values of the month June were evaluated. For this in each classroom 2-3 sensors where installed.

3.3.1. Measuring devices

Data logger HOBO from "Onset Computer Corporation" and the CO_2-Logger WÖHLER Model CDL 210 from "Wöhler Messgeräte Kehrgeräte GmbH" were the two sensors used for the measurements.

Figure 24: Sensors used for the measurements

3.3.1.1. HOBO Temperature

The HOBO U12 Temperature Data Logger is a single-channel logger for high-accuracy temperature monitoring and can record up to 43,000 12-bit measurements. The U12-001 Data Logger is for use in Indoor environments. The logger uses a direct USB interface for launching and data readout by a computer.

Measurement range:

Temperature: -20° to 70°C (-4° to 158°F)

Accuracy:

Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)

3.3.1.2. HOBO Temperature/Relative Humidity/Light/External Data Logger

The HOBO U12 Temperature/Relative Humidity/Light/External Data Logger is a four-channel logger with 12-bit resolution and can record up to 43,000 measurements or events. The external channel accepts a variety of sensors, including temperature, and split-core AC current sensors as well as 4-20 mA and voltage input cables (sold separately). The logger uses a direct USB interface for launching and data readout by a computer.

Measurement range:

Temperature: -20° to 70°C (-4° to 158°F)
RH: 5% to 95% RH
Light intensity: 1 to 3000 foot-candles (lumens/ft2) typical; maximum value varies from 1500 to 4500 foot-candles (lumens/ft2)

Accuracy:
Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)
RH: ±2.5% from 10% to 90% RH (typical), to a maximum of ±3.5%
Light intensity: Designed for indoor measurement of relative light levels, see Plot D for light wavelength response

3.3.1.3. WÖHLER

The Wöhler CO_2-logger measures the CO_2 level, the air temperature and the humidity and logs the measured data. It is therefore ideal for the monitoring and the evaluation of the interior climate in living spaces and in commercial premises.

Measurement range:

CO_2: 0 – 6.000 ppm (9.999 ppm)
Temperature: -10 °C to +60 °C
RH: 5% to 95% RH
Accuracy:
CO_2: 50 ppm, ± 5 % of reading
Temperature: ± 0, 6 °C
RH: ± 3 % (10 – 90 %), 5 % (other values)

3.4. Questionnaire

To help understand the results of the analysis the teachers in each school were handed a questionnaire at the end of school semester in June as shown in appendix.

Inter alia information such as their ventilation method, air quality, light and temperature comfort and the degree of the humidity in the classrooms were subjects of enquiry. The Teachers were also questioned about their health problems potentially resulting from elevated CO_2 levels in the schoolrooms.

3.5. Analysis

The temperature, humidity and CO_2 values of the twenty chosen classrooms (4 classes from each school) were measured by two temperature measuring sensors, one of them also measured the humidity, and the third sensor the CO_2 values. The two temperature values showed a difference of ±1°C and in all analyses the mean temperature of the two was applied. The outcome of the measurement was analyzed by standard tools as described in the following:

3.5.1. Types of analysis

3.5.1.1. Cumulative frequency distribution graphs

Cumulative frequency analysis is performed to obtain insight into how often a certain phenomenon (feature) is below a certain value. In our case Temperature, humidity and CO_2 values were analysed with this method. The results are in percentage in the chosen time span and the bins are as following:

Table 9: Bins for cumulative histograms

	Bins
Temperature	<11 <12 <13 <14 <15 <16 <17 <18 <19 <20 <21 <22 <23 <24 <25 <26 <27 <28 <29 <30 <31
Relative humidity	<5 <10 <15 <20 <25 <30 <35 <40 <45 <50 <55 <60 <65 <70 <75
absolute humidity	<3 <4 <5 <6 <7 <8 <9 <10 <11 <12 <13 <14 <15 <16 <17 <18
CO_2	<200 <300 <400 <500 <600 <700 <800 <900 <1000 <1100 <1200 <1300 <1400 <1500 <1600 <1700 <1800 <1900 <2000

3.5.1.2. Scatter plot

The data points of CO_2 values are displayed as a collection of points, each having the value of one variable (CO_2) determining the position on the horizontal axis and the value of the other variable (Temperature or relative humidity) determining the position on the vertical axis. The Coefficient of determination R^2 is most often seen as a number between 0 and 1.0, used to describe how well a regression line fits a set of data. An R^2 near 1.0 indicates that a regression line fits the data well, while an R^2 closer to 0 indicates a regression line does not fit the data very well (Steel und Torrie 1960).

3.5.1.3. Box plot

A box plot is a convenient way of graphically depicting groups of numerical data through their five-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum). A box plot may also indicate which observations, if any, might be considered outliers.

Box plots display differences between populations without making any assumptions of the underlying statistical distribution: they are non-parametric. The spacings between the different parts of the box help indicate the degree of dispersion (spread) and skewness in the data, and identify outliers. Skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable. This tool was used to show reference days (24 hours: x axis) with Temperature and CO_2 as y axis.

3.5.1.4. Line chart

Assembling the median values of temperature or CO_2 (resulting from the box plots) to compare the different schools and illustrating them in a line chart with time as x axis and temperature or CO_2 value as y axis was also a tool used in the next section; Results and discussion.

For the user evaluation the results of the questionnaires were also shown with this tool.

3.5.1.5. Psychrometric charts

A psychrometric chart presents physical and thermal properties of moist air in a graphical form. By choosing the Adaptive method at the very top of the user interface, the chart changes and the input variables include air temperature, mean radiant temperature and prevailing mean outdoor temperature. This is because the personal factors and humidity are not significant in this method since adaptation is considered, and the only variable is the outdoor temperature.[1]

This method accommodates the design of naturally ventilated buildings. In these buildings, occupants are comfortable over an even wider range of thermal conditions than can be predicted by chamber studies or field studies of occupants of climate controlled buildings. This method recognizes the role not only of adaptation but of self-mitigating strategies such as opening user-accessible windows (Turner und Stephen 2011).

The indoor temperatures, relative humidity, mean monthly outside temperature were the given input to a *Matlab* based script and the output are presented in monthly based charts. In another approach the ÖNORM helped defining the borders of the comfort zone. Both results presented in the Section 3.5.1.5.

In the Psychrometric charts, data points lying within and around the so called comfort zone are shown. The comfort zone is a two dimensional area that is calculated using temperature and humidity parameters. The data points that lie within the comfort zone are considered as comfortable. The extent of the comfort zone was obtained as follows. For each moth the mean outdoor temperature was used to compute the neutrality temperature and the extent of the comfort zone on Psychrometric charts according to (Szokolay 2004).

[1] http://www.cbe.berkeley.edu /comforttool/media/html/help.html

4. RESULTS AND DISCUSSIONS

4.1. Overview

As mentioned in the previous chapter, the three indoor quality-and building performance indicators; air temperature, relative humidity and carbon dioxide level were measured every 10 minutes for the period of five month (CO_2 values for one month). This chapter summarizes the main results divided into three parts consisting of temperature, humidity, and carbon dioxide level. Each part includes the monthly results or measurements over the entire considered period. For a better understanding of the graphs, the abbreviations introduced in the previous chapter are utilized.

The mean outside temperature and external relative humidity are shown in Figure 25 to have an impression of the outside thermal conditions during the five measurement months.

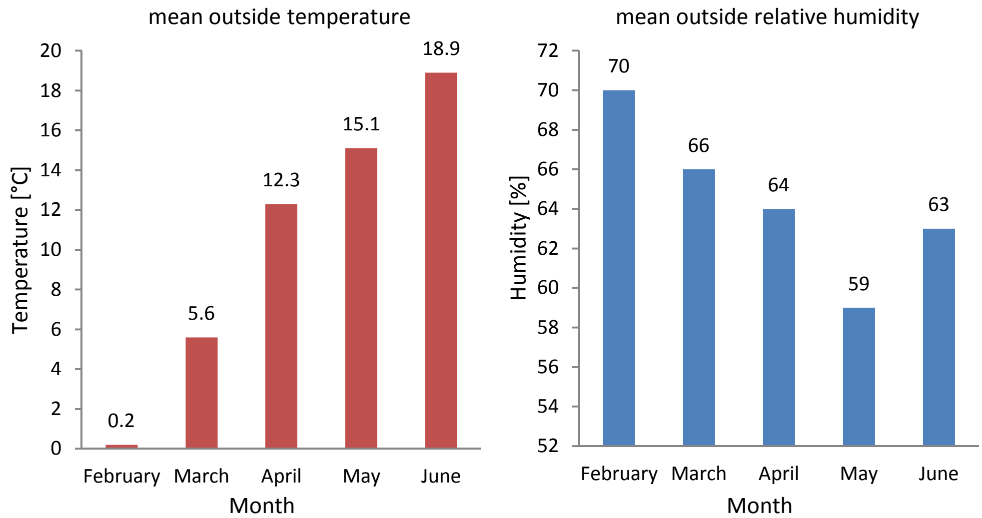

Figure 25: Bar charts of the outside thermal conditions in Baden

As it can be seen in Figure 25, the outside temperature varies in the measurement period about 19 °C, and the external relative humidity differs by eleven percent.

4.2. **Air Temperature**

This section contains evaluations and analysis of the air temperature (dry bulb) measured by the Hobo sensors installed in the classes.

It should be noted that here the 24 hour measurements were mainly reduced to their common opening school hours and days, in order to be able to have a correct and comparable picture of the thermal condition of the schools.

Figure 26 shows the entire period of observation (from February to the end of June) to be able to perceive the outline of the borders from the assembled data.

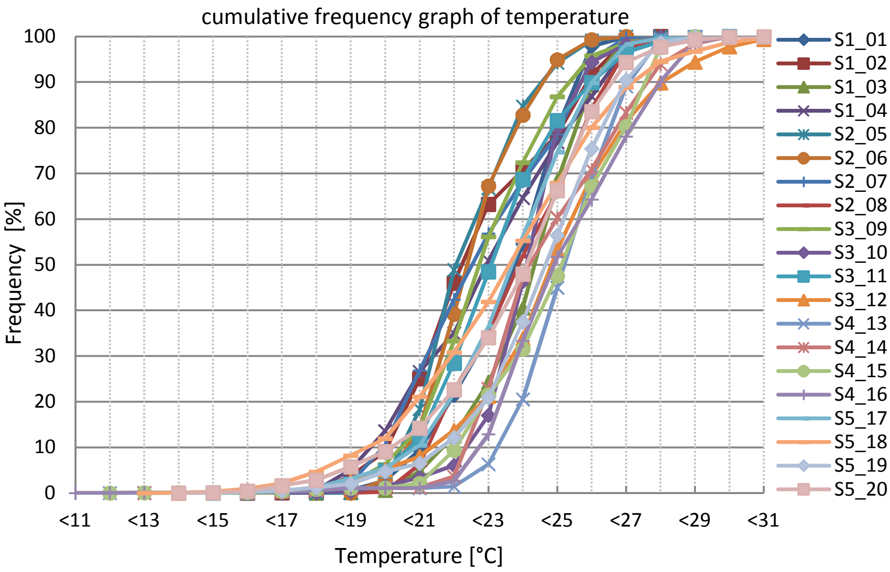

Figure 26: Cumulative frequency graph of temperature in all 20 classes

As it can be seen in Figure 26, these temperature borders vary between 11°C to 31 °C.

4.2.1. Monthly comparative analysis of temperature

February was the first month of measurement, with an outdoor mean temperature of 0.2 °C.

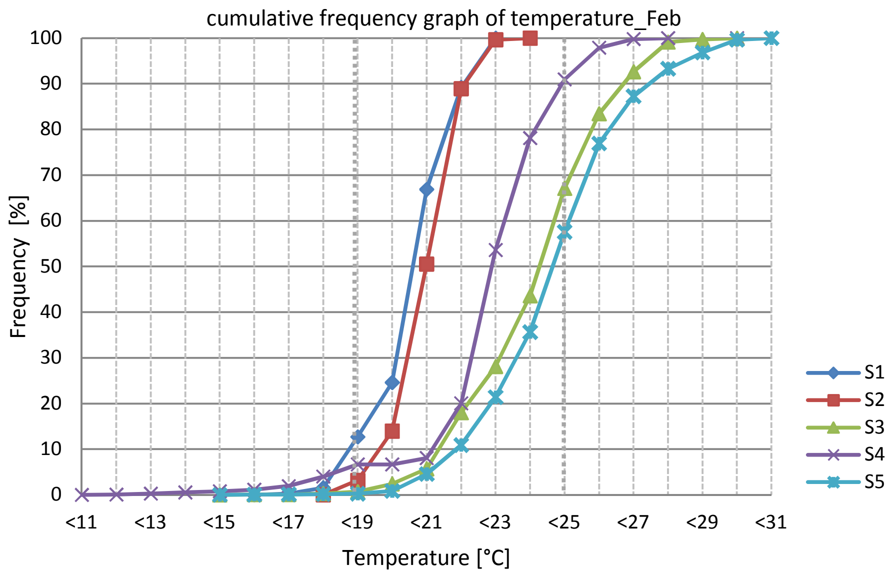

Figure 27: Cumulative frequency graph of temperature for 5 schools during school time (8:00-13:00) in February 2011

Figure 27 reveals that during the school opening hours, the container schools S3 and S5 have very similar frequencies of temperatures which are almost more 60 % of the time less than 25°C. Both have very high temperatures for the winter season in the remaining time (33-42%).

On the other hand, the remaining schools were mostly slightly cooler but do more or less lie in the norm required range. S1 seems to have the most percentage of the lower temperatures (13%) though, 11 % of the data lie between 18-19 °C.

For a better comparison of the considered schools, the temperatures lying out of the norm are shown in Table 10.

Table 10: Temperature percentage which lay out of the necessary range according to ÖNORM EN ISO 7730 (Category C) assuming operative temperature equals dry bulb temperature

	S1	S2	S3	S4	S5
<19 °C	13%	3%	1%	7%	0%
>25 °C	0%	0%	33%	9%	42%

March was the second month of measurement in the heating season, with an outdoor mean temperature of 5.6 °C.

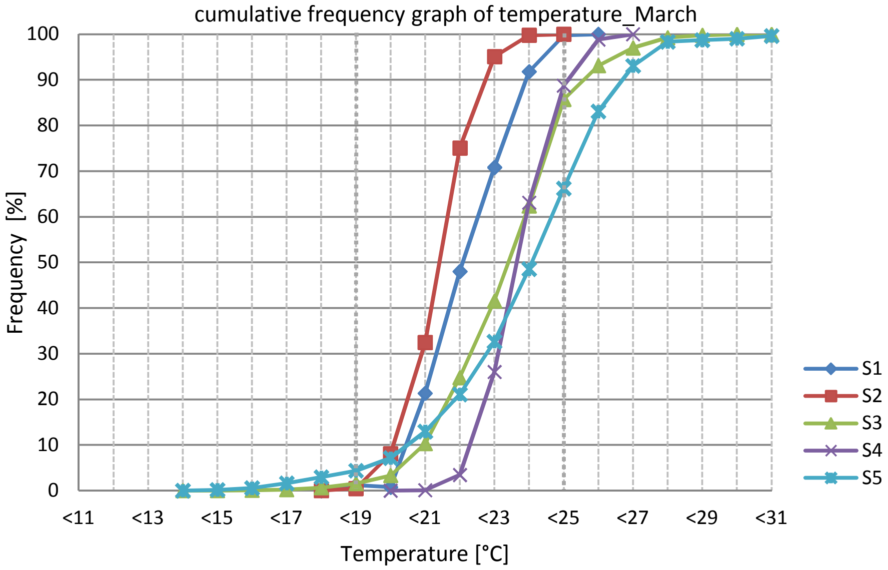

Figure 28: Cumulative frequency graph of temperature for 5 schools during school time (8:00-13:00) in March 2011

Figure 28 displays a shift of Schools S1, S2 and S4 towards higher temperatures, the container schools S3 and S5 have now a frequency of 84% and 62% in the enquired range of 19°C-25°C.

All schools have more or less, temperatures above 19 degrees and they seem to have a better thermal comfort condition. Thought the container schools have remained warm in comparison to February.

S1 and S2 lay both the entire school time in the given range.

For a better evaluation of the five schools, the temperatures lying out of the norm are shown in Table 11.

Table 11: Temperature percentage which lay out of the necessary range according to ÖNORM EN ISO 7730 (Category C) assuming operative temperature equals dry bulb temperature

	S1	S2	S3	S4	S5
<19 °C	1%	0%	2%	0%	4%
>25 °C	0%	0%	14%	11%	34%

April was the third measurement month in the heating season, with an outdoor mean temperature of 12.3 °C.

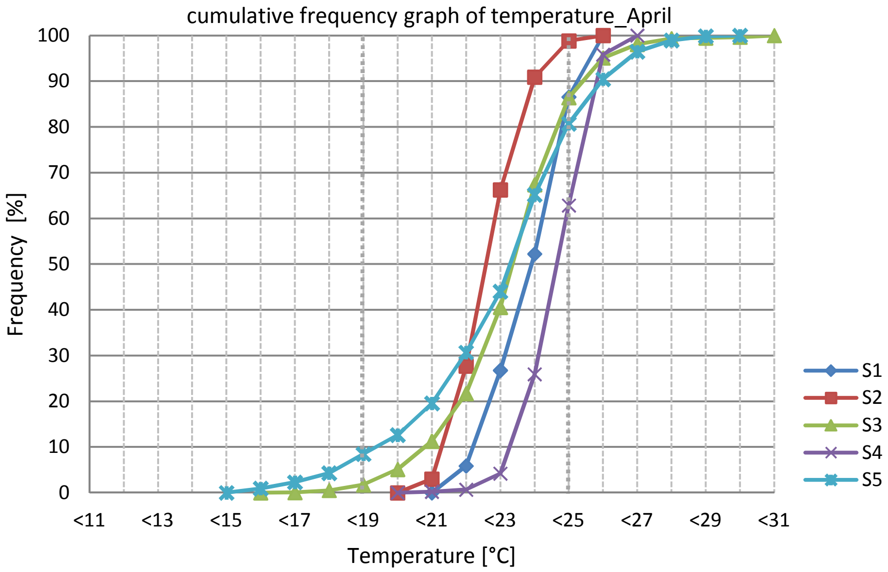

Figure 29: Cumulative frequency graph of temperature for 5 schools during school time (8:00-13:00) in April 2011

Figure 29 displays a further shift towards higher temperatures in Schools S1, S2 and S4. This can be easily observed in Table 12. The temperatures of the container school S3 were more or less the same as in March, while in S5 they showed a slight shift to the lower temperatures.

This drop of the temperature in the S5 container classes could result from the construction material (higher U-values than in normal schools) of the classrooms. The radiant temperature is in direct relation with the temperature difference of inside and outside air and the U-value of the building construction. A higher difference between inside air temperature (in colder months) and the radiant temperature of the surrounding surfaces may result in discomfort of the occupants. The occupants of the classes increase the electric-heating when they feel uncomfortable. The warmer the outside temperature gets, the less do occupants feel cold; consequently they do not heat the classroom as much.

As shown in Table 12 in April, S2 had the best values, while S4 and S5 had the worst thermal comfort with 27% of the values lying outside of required the norm.

Table 12: Temperature percentage which lay out of the necessary range according to ÖNORM EN ISO 7730 (Category C) assuming operative temperature equals dry bulb temperature

	S1	S2	S3	S4	S5
<19 °C	0%	0%	2%	0%	8%
>25 °C	13%	1%	14%	37%	19%

May was the 4th measurement month in the heating season, with an outdoor mean temperature of 15.1 °C.

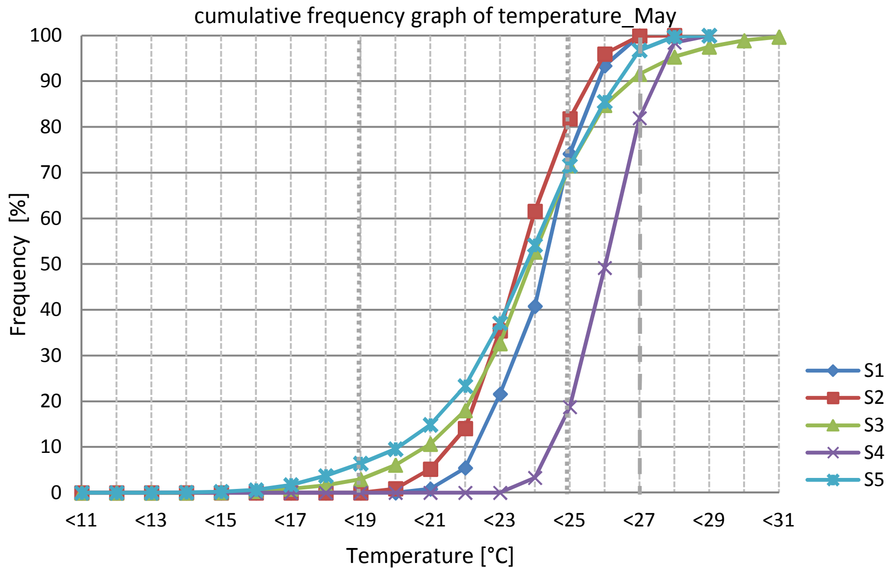

Figure 30: Cumulative frequency graph of temperature for 5 schools during school time (8:00-13:00) in May 2011

Figure 30 displays the next shift towards higher temperatures in all the schools, particularly in S4. This is clearly visible from Table 13, considering the change of 37% in April to 81% frequency of temperatures above 25°C in May. This may lay in the heating regulation problems which school 5 had in this period. In S5 the heating temperatures had to be frequently adjusted and the school was often overheated.

The mean outside temperature in Baden in May 2011 varied from 13.5°C to 19.7°C from 7-14 o'clock. The HDD $_{20/12}$ value of this month was around 40; in other words May was a transition month between the heating period and the summer season.

The mentioned borders from ÖNORM (ÖNORM EN ISO 7730, 2006) were separated in two groups of winter and summer seasons, combining the two we may consider the borders of 19-27 °C. Considering the defined borders, S1 and S2 were completely in the specified range. S4 shows an unusual high temperature and the two container schools S3 and S5 had diversions of less than 10%, as shown in Table 13.

Table 13: Temperature percentage which lay out of the necessary range according to ÖNORM EN ISO 7730 (Category C) assuming operative temperature equals dry bulb temperature

	S1	S2	S3	S4	S5
<19 °C	0%	0%	3%	0%	6%
>25 °C	26%	18%	28%	81%	28%
>27 °C	0%	0%	8%	18%	3%

June was the 5th measurement month in the summer season, with an outdoor mean temperature of 18.9 °C.

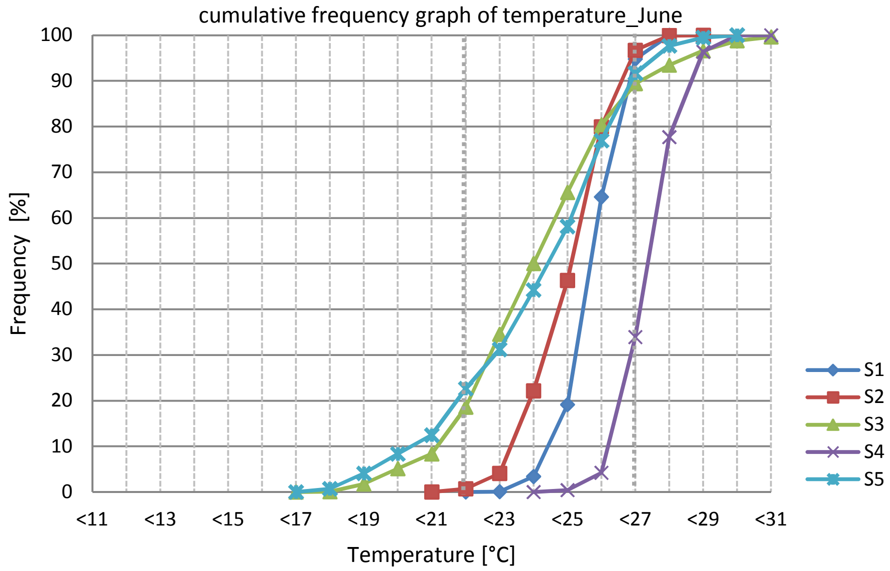

Figure 31: cumulative frequency graph of temperature for 5 schools during school time (8:00-13:00) in June 2011

Figure 31 present the next shift towards higher temperatures particularly in S4 with 66% of the data points above 27°C whereupon the least increase is seen in the container classes particularly S3.

The magnitude of HDD $_{20/12}$ in June was null (0), therefore it is considered as summer season with a comfort temperature range of 22-27 °C (ÖNORM EN ISO 7730).

Considering the new borders, S1 and S2 are more or less in the given range. S4 is still showing an unusual high temperature and the two container schools, S3 and S5, have diversions of about 10% lower temperatures than in norm.

For a better evaluation the temperatures lying out of the norm in June are shown in Table 14.

Table 14: Temperature percentage which lay out of the necessary range according to ÖNORM EN ISO 7730 (Category C) assuming operative temperature equals dry bulb temperature

	S1	S2	S3	S4	S5
<22 °C	0%	1%	19%	0%	23%
>27 °C	5%	3%	11%	66%	8%

4.2.2. **Monthly reference days of the schools for the temperature median**

The temperature values during the reference day in each month represent the entire period of the particular month. Figure 32 to Figure 36 display the median of the measured data points in the particular month.

It is significant to notice that the median of container schools has a shift to the lower temperatures from February to April, contrary to the other schools (S1, S2 and S4).

In May and June the medians are more or less in the same range of temperature, and the schools are not much different from each other. The graphs show a great change of temperature in S3 and S5 during the reference days of May and June. In April is this change of temperature of the median in S5 even 7°C.

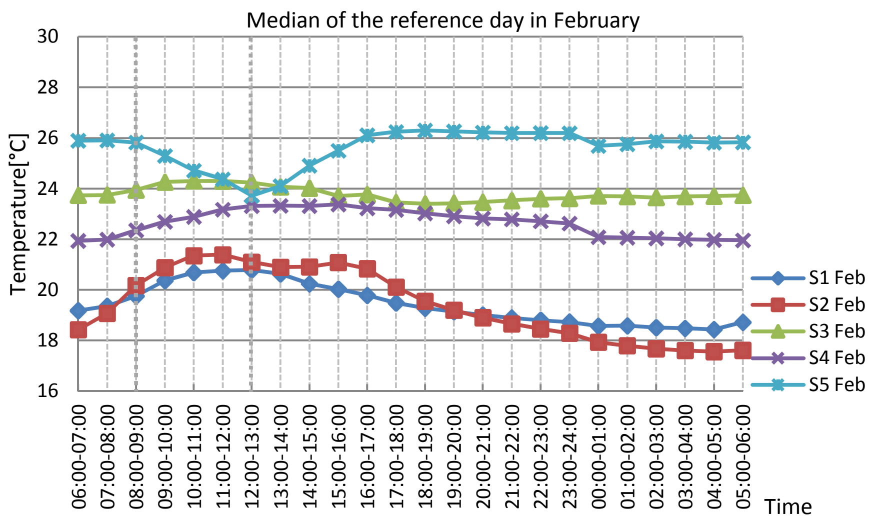

Figure 32: Temperature median of the reference day in February

In February all normal schools start getting warmer around 5 o'clock, as the heating system in these schools are set to change from 18°C to 22°C at this time (5:00).

Interesting to note is that in the school opening hours (8:00-13:00), the temperature of S5 gets contrary to the other school, continually cooler. The same trend continues also in March in the S5. This trend cannot be observed in S3.

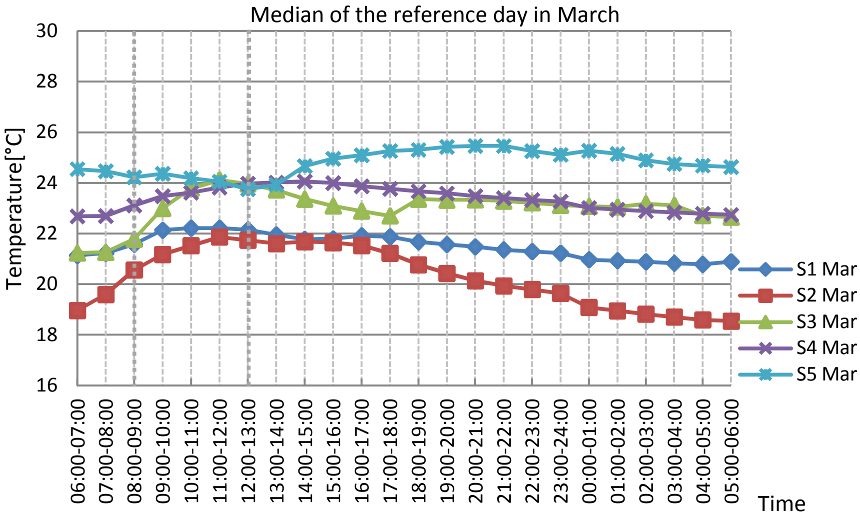

Figure 33: Temperature median of the reference day in March

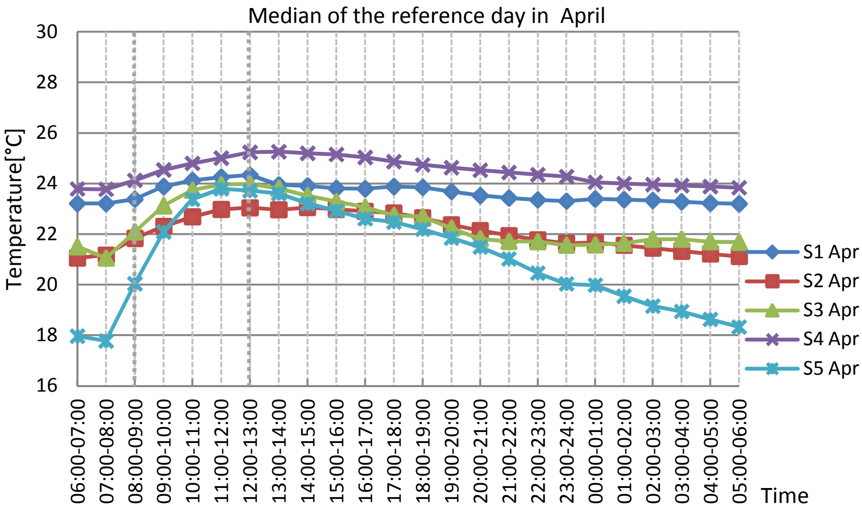

Figure 34: Temperature median of the reference day in April

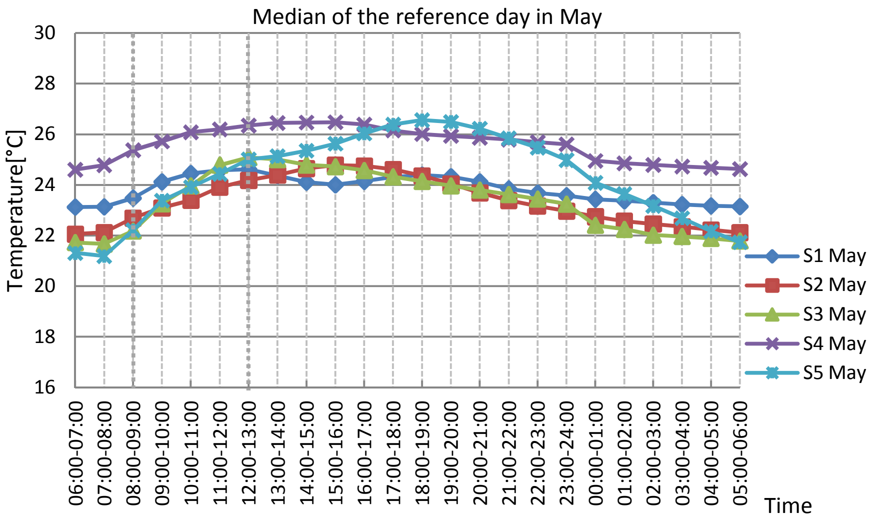

Figure 35: Temperature median of the reference day in May

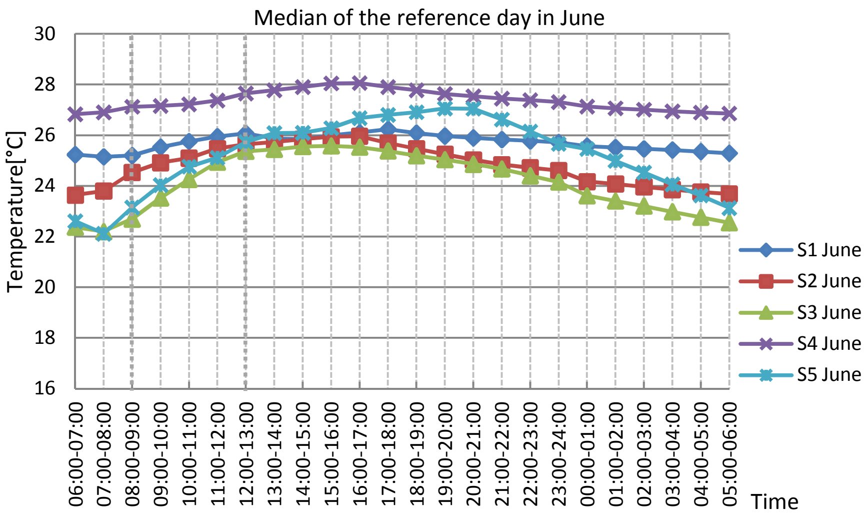

Figure 36: Temperature median of the reference day in June

4.3. **Operative Temperature**

In order to figure out the difference the building envelopes make, especially because this is one of the main differences of the compared schools, the operative temperature or effective temperature is calculated as shown in Table 15. As mentioned before according to ÖNORM, at or near comfort levels the difference between air temperature and the mean radiant temperature should not be greater than about 2°K (ÖNORM EN ISO 7730, 2006).

4.3.1. Calculation of the operative temperatures of S2 and S5 in February 4th (10:10)

According to the calculations the difference between the radiant temperature and air temperature in S5 is 1.15 °C and in S2 it equal to 0.44°C. The thermal comfort in the classes depends on the operative temperature which should lie in the defined comfort zones. The average temperature of the surrounding surfaces should be of the same level as the air temperature.

Table 15: Comparison of the operative temperatures of S2 and S5 in Feb. 4th 10:10

S5_501	Component	T_{si} [°C]	T_i [°C]	T_e [°C]	U [W/m²K]	R_{si}[m²K/W]	S [m²]	T_{si} x S
1	windows	22.40	25.54	3.60	1.10	0.13	9.07	203.24
2	inside wall I	24.18	25.54	3.60	1.89	0.13	21.38	516.82
3	inside wall II	24.67	25.54	3.60	1.89	0.13	12.94	319.17
4	outside wall	24.48	25.54	3.60	0.37	0.13	25.24	618.01
5	ceiling	24.48	25.54	3.60	0.37	0.13	54.63	1337.48
6	floor	24.60	25.54	3.60	0.33	0.13	54.63	1343.71
							T_{si} [°C]	24.39
							T_i [°C]	25.54
	04.02.2011 10:10						T_u [°C]	24.97

S2_204	Component	T_{si} [°C]	T_i [°C]	T_e [°C]	U [W/m²K]	R_{si}[m²K/W]	S [m²]	T_{si} x S
1	windows	17.96	20.88	3.60	1.30	0.13	18.48	331.89
2	inside wall I	20.82	20.88	3.60	0.50	0.13	28.08	584.70
3	inside wall II	20.91	20.88	3.60	0.50	0.13	20.75	433.76
4	outside wall	20.43	20.88	3.60	0.20	0.13	31.84	650.51
5	ceiling	20.39	20.88	3.60	0.22	0.13	61.50	1253.73
6	floor	20.92	20.88	3.60	0.30	0.13	61.50	1286.40
							T_{si} [°C]	20.44
							T_i [°C]	20.88
	04.02.2011 10:10						T_u [°C]	20.66

4.3.2. Calculation of the operative temperatures of S2 and S5 in June 10th (10:10)

The difference between the radiant temperature and air temperature in S5 is 0.22 °C and in S2 it equal to 0.29 °C.

To calculate the T_{si} of each construction element represented in Table 16 the following formula was used:

$$Tsi = Ti - U \times Rsi \times (Ti - Te)$$

Table 16: Comparison of the operative temperatures of S2 and S5 in June10th 10:10

S5_501	Component	T_{si} [°C]	T_i [°C]	T_e [°C]	U [W/m²K]	R_{si}[m²K/W]	S [m²]	T_{si} x S
1	windows	22.04	22.50	19.30	1.10	0.13	9.07	199.97
2	inside wall I	21.89	22.50	19.30	1.89	0.13	21.38	467.81
3	inside wall II	22.38	22.50	19.30	1.89	0.13	12.94	289.50
4	outside wall	22.35	22.50	19.30	0.37	0.13	25.24	564.03
5	ceiling	22.35	22.50	19.30	0.37	0.13	54.63	1220.65
6	floor	22.36	22.50	19.30	0.33	0.13	54.63	1221.56
							T_{si} [°C]	22.28
							T_i [°C]	22.50
	10.06.2011 10:10						T_u [°C]	22.39

S2_204	Component	T_{si} [°C]	T_i [°C]	T_e [°C]	U [W/m²K]	R_{si}[m²K/W]	S [m²]	T_{si} x S
1	windows	24.78	25.90	19.30	1.30	0.13	18.48	458.02
2	inside wall I	25.52	25.90	19.30	0.50	0.13	28.08	716.50
3	inside wall II	25.60	25.90	19.30	0.50	0.13	20.75	531.14
4	outside wall	25.73	25.90	19.30	0.20	0.13	31.84	819.19
5	ceiling	25.71	25.90	19.30	0.22	0.13	61.50	1581.24
6	floor	25.74	25.90	19.30	0.30	0.13	61.50	1583.09
							T_{si} [°C]	25.61
							T_i [°C]	25.90
	10.06.2011 10:10						T_u [°C]	25.75

4.4. Relative Humidity

This section contains some graphs showing the cumulative humidity distribution of the observed classrooms of the five schools. Figure 37 shows the borders of the measurement during the 5 month period of observation (February until end of June).

The rest of the graphs shown in this section consist of data points which lay in the common opening hours (8:00-13:00) and days of the chosen schools.

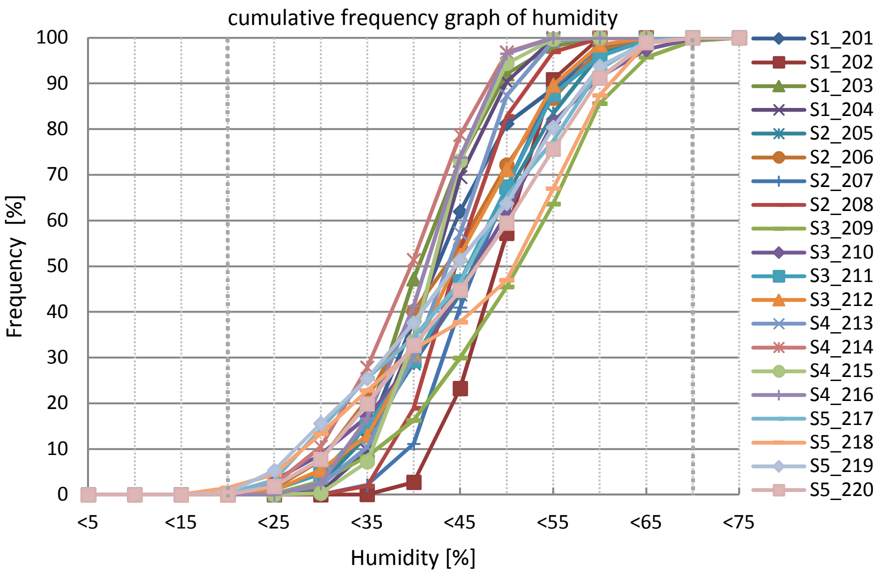

Figure 37: Cumulative frequency graph of humidity of all 20 classes in the 5 schools

4.4.1. Monthly comparative analysis between the schools

In the graphs of this section, the borders defined in ÖNORM are marked as dashed grey lines. As it can be seen from Figure 38, all schools lay in the specified interval of 20-60% relative humidity.

In February the container schools S3 and S5 have 6-11% of the measured data below 25 % which is too dry if the standard temperature of 20-22 °C would have been maintained.

As we mentioned in Section 4.2.1, both schools had very high temperatures for the winter season (33-42% of the time over 25°C). Therefore the 6-11 % relative humidity which is lying between 20 and 25 °C should be considered more closely and cannot be evaluated for certain as dry.

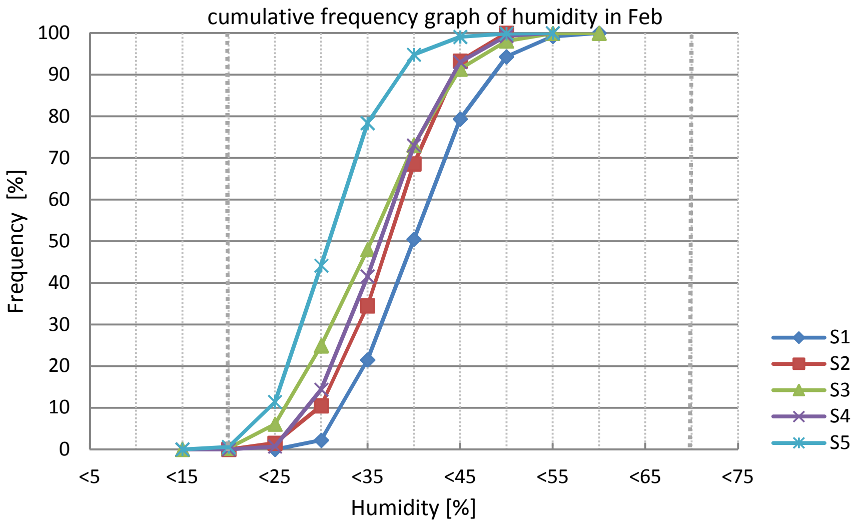

Figure 38: Cumulative frequency graph of humidity of 5 schools during school time (8:00-13:00) in February

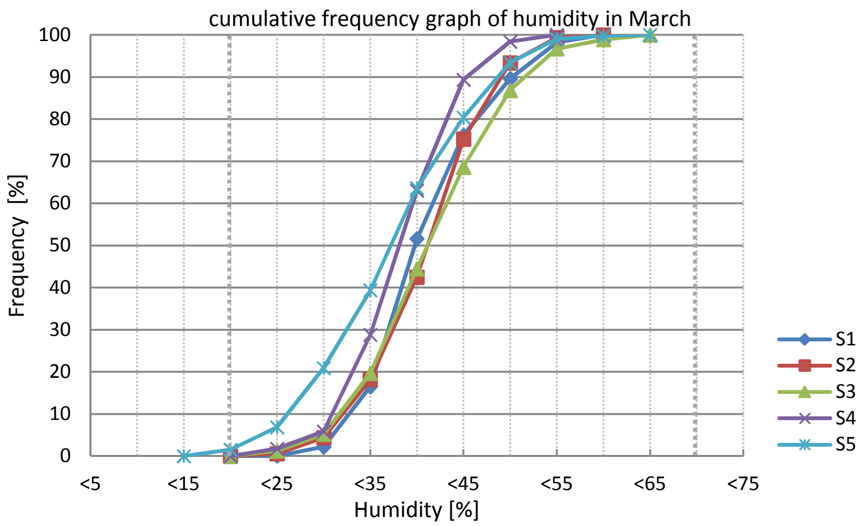

Figure 39: Cumulative frequency graph of humidity of 5 schools during school time (8:00-13:00) in March

The same proposition may be asserted for the 7% of the measured data in March, which were below 25 % relative humidity in S5.

In the rest of the measuring period, all schools had values between 25-65% relative humidity as one can see from Figure 40 to Figure 42.

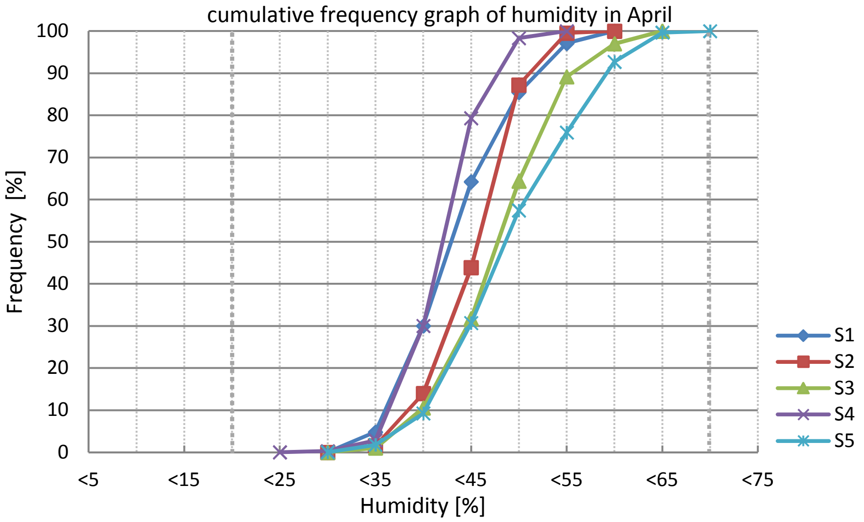

Figure 40: Cumulative freq. graph of humidity of 5 schools during school time (8:00-13:00) in April

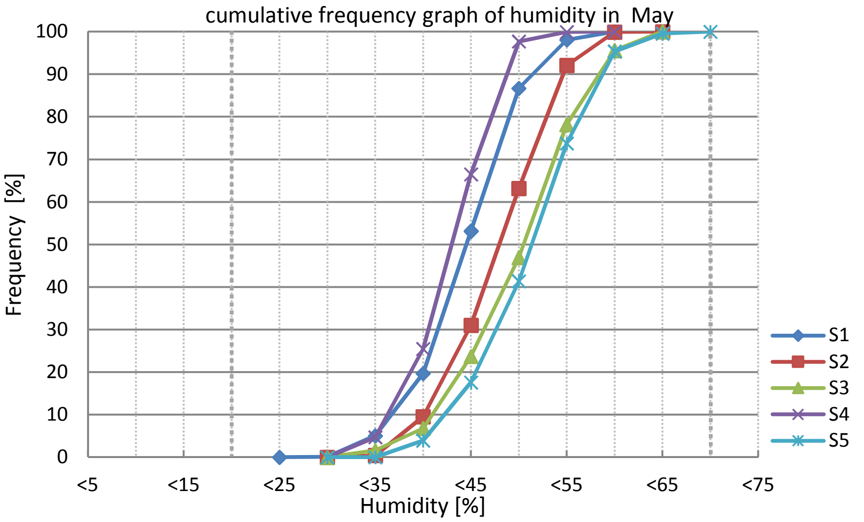

Figure 41: Cumulative freq. graph of humidity of 5 schools during school time (8:00-13:00) in May

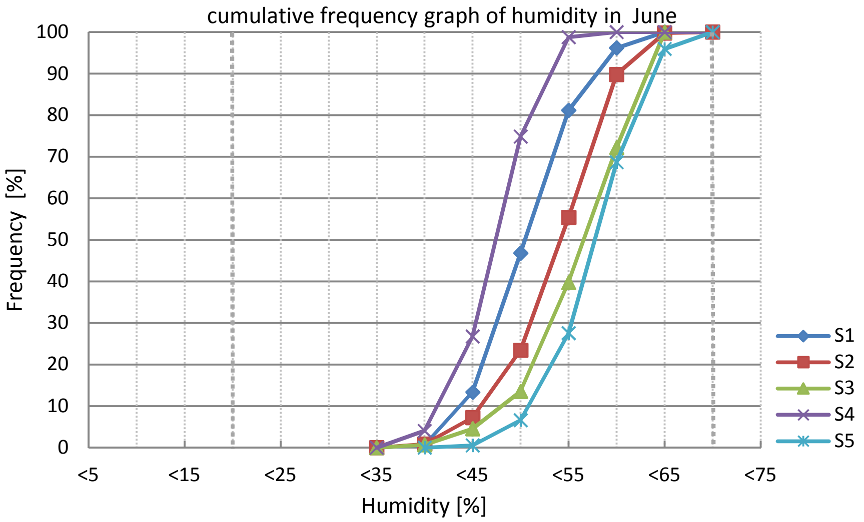

Figure 42: Cumulative freq. graph of humidity of 5 schools during school time (8:00-13:00) in June

4.5. Absolute Humidity

The absolute humidity values of all the 20 classes in the measurement period are presented in Figure 43. An absolute humidity of 14 grams of water vapour per m³ air is considered as a possible limit (12 g/kg in ÖNORM).

This shows the entire period of observation (February until the end of June) to be able to perceive the outline of the borders from the assembled data.

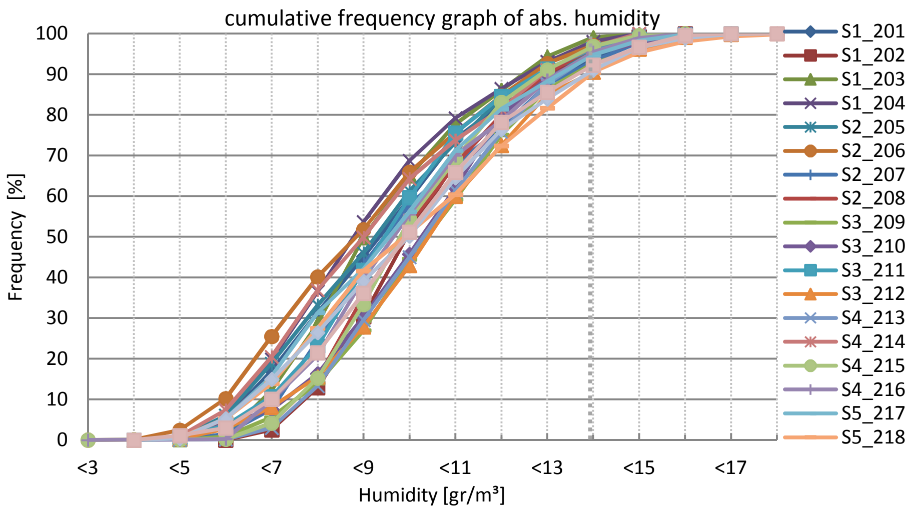

Figure 43: Cumulative frequency graph of absolute humidity of all the 20 classes

Figure 43 to Figure 48 contain data points of the absolute humidity which lay in the common opening hours (8:00-13:00) and days of all the 5 schools in the measurement period.

During the heating season (February to April) no school had data points of absolute humidity higher than 14 g/m³. Only 0.2 % of the measured data points of S5 were between 14-15 g/m³.

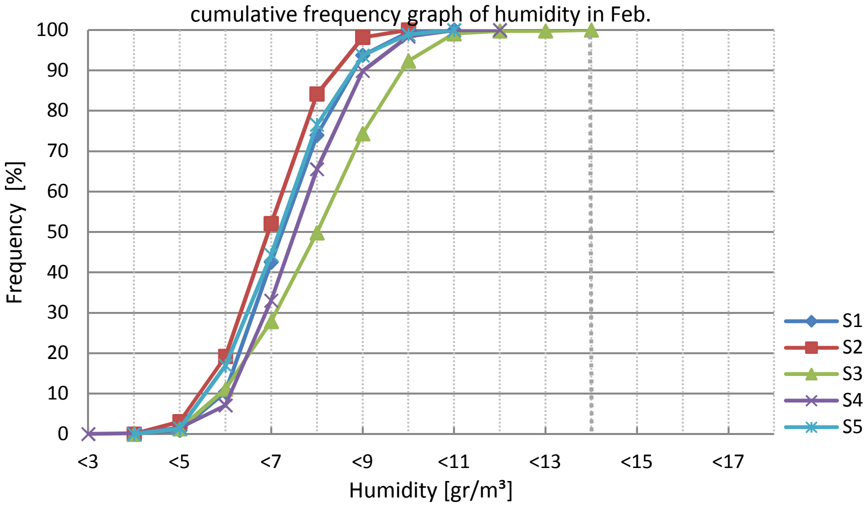

Figure 44: Cumulative frequency graph of absolute humidity of 5 schools during school time (8:00-13:00) in February 2011

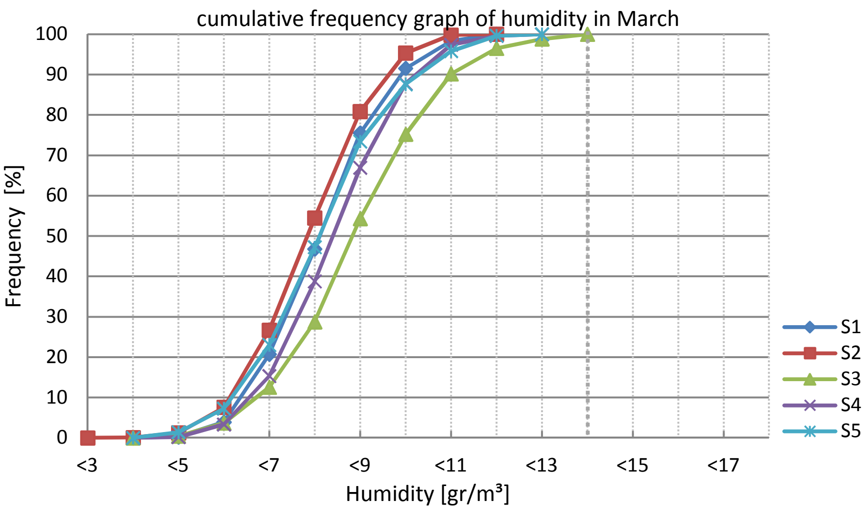

Figure 45: Cumulative frequency graph of absolute humidity of 5 schools during school time (8:00-13:00) in March 2011

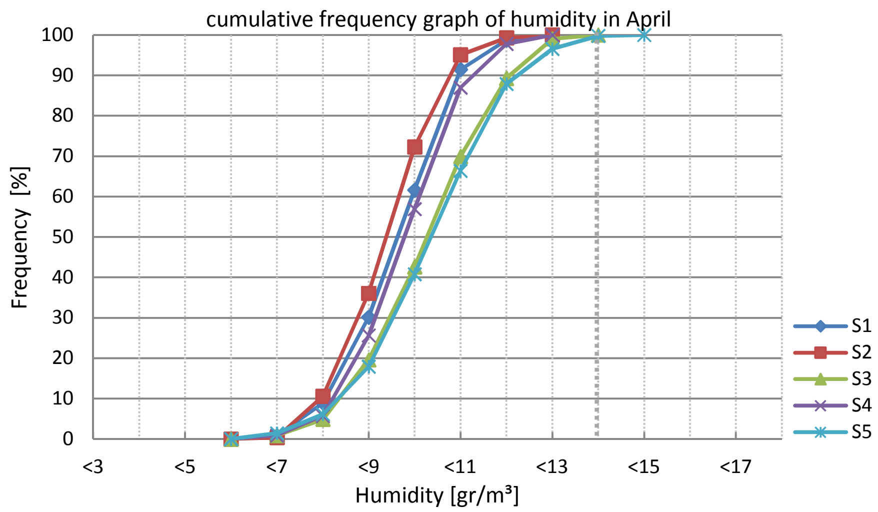

Figure 46: Cumulative frequency graph of absolute humidity of 5 schools during school time (8:00-13:00) in April 2011

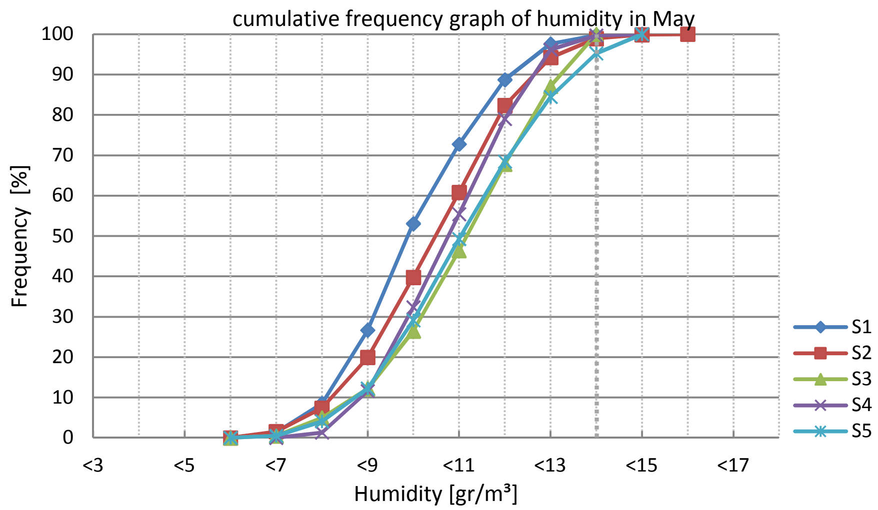

Figure 47: Cumulative frequency graph of absolute humidity of 5 schools during school time (8:00-13:00) in May 2011

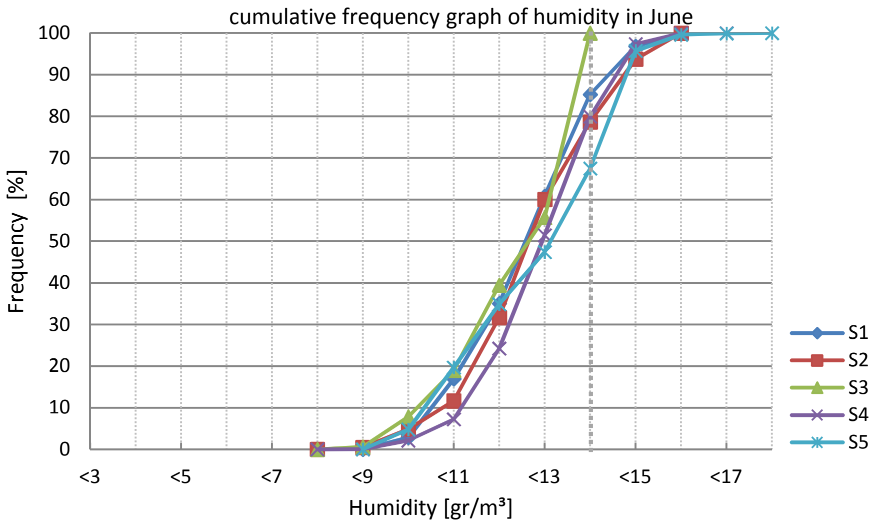

Figure 48: Cumulative frequency graph of absolute humidity of 5 schools during school time (8:00-13:00) in June 2011

During the non heating season (May to June) particularly in June, S5 had 32.5 % of the time data laying out of the defined range, which indicates a rather humid air in the classes.

For a better evaluation, absolute humidity percentages which lay out of the necessary range according to ÖNORM (12g/kg) are shown in Table 17 (ÖNORM EN ISO 7730, 2006).

Table 17: Absolute humidity percentage which lay out of the necessary range according to ÖNORM EN ISO 7730 (12g/kg)

	S1	S2	S3	S4	S5
< 14 g/m³ in May	0%	1%	0%	0%	5%
< 14 g/m³ in June	15%	21%	0%	20%	32,5%

4.6. Indoor Air Quality

The ÖNORM EN 13779:2008 proposes for rooms with predominant emissions by individuals (like classrooms) CO_2 concentrations as ventilation parameter. This section is describing the indoor air quality on hand of the different graphs displaying the CO_2 concentrations in eight of the chosen classrooms. All the examined schools were naturally ventilated therefore the difference between the CO_2 values are probably dependent on factors as; the occupant's behaviour, their age, activity and occupancy amount, the size of the classroom and its tightness, the windows and the airing possibilities.

4.6.1. Cumulative frequency graph in June

This part the graph shows the CO_2 concentration in June 2011 during school time (8:00-13:00) in eight of the chosen classes.

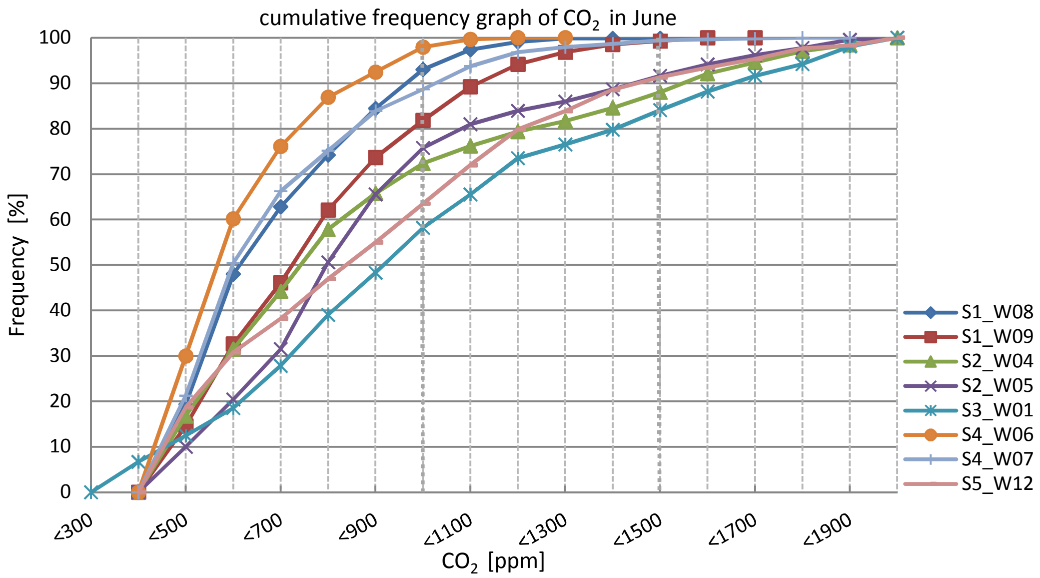

Figure 49: Cumulative frequency graph of CO_2 in June 2011 during school time (8:00-13:00) in 8 chosen classes

S3 had the maximum CO_2 concentration in both intervals. Both S3 and S5 have around 40 percent of the measured data points are over the Pettenkofer threshold of 1000 ppm. This may be due to the bad ventilation behaviour of the users or/and the small classroom air volume with 5.9 m³ per pupil.

Table 18: Percentage of data lying out of recommended CO_2 concentrations in norm

	S1_W08	S1_W09	S2_W04	S2_W05	S3_W01	S4_W06	S4_W07	S5_W12
>1000	7	18	28	24	42	2	11	37
>1500	0.2	0.8	12	8	16	0	0.6	9

As mentioned before for classrooms of a secondary school in the ÖISS (ÖISS 2012) an air volume of 8 m³ (6 m³ for elementary schools) is proposed. This means with a usual volume of 136 m^3 the container classes should be occupied by maximum 16 pupils in a high school like S5 and 22 pupils in S3.

The best air quality is measured in both S4 classes and a classroom in S1. The 1500 ppm value has not been exceeded more than 1%, which shows a good air quality and ventilation behaviour in general.

4.6.2. **Scattered plots for June**

In the following, two scattered graphs are presented to detect the correlation between our measured values in June. Figure 50 and Figure 51 display that in general no remarkable correlation between CO_2 level and temperature or relative Humidity can be observed.

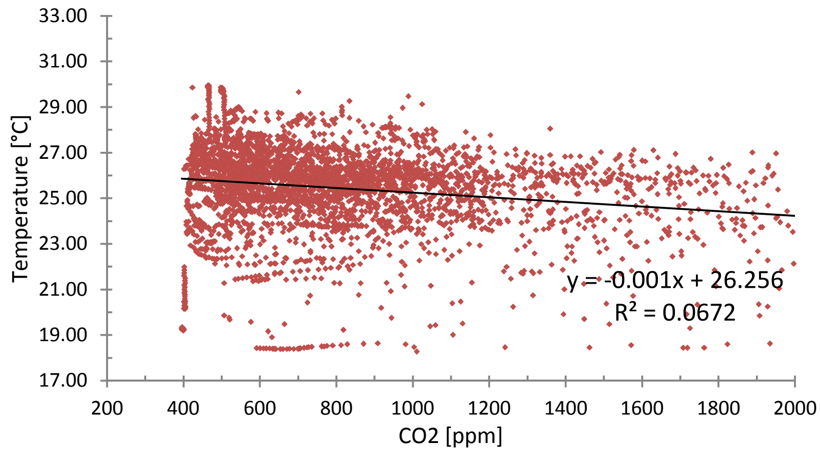

Figure 50: Correlation between CO_2 concentration and indoor temperature in all 5 schools in June

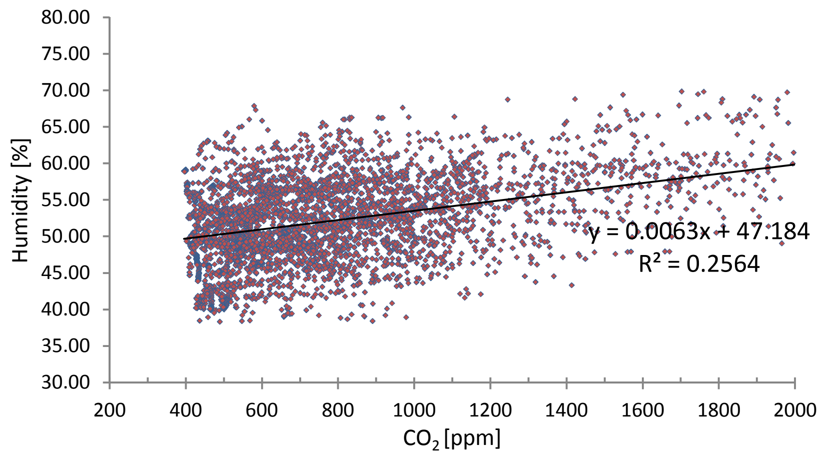

Figure 51: Correlation between CO_2 concentration and indoor relative humidity in all 5 schools in June

4.6.3. **Box plots of a reference day for June**

As mentioned in section 3.5.1.3, the spacing (of box plots) between different parts of the box help to specify the degree of dispersion (spread) and skewness in the data, and identify outliers. Following graphs present this spread of data in June for the eight chosen classrooms of the five schools by a statistical evaluation of the hourly CO_2 values with the help of a five number summary displayed as a boxplot.

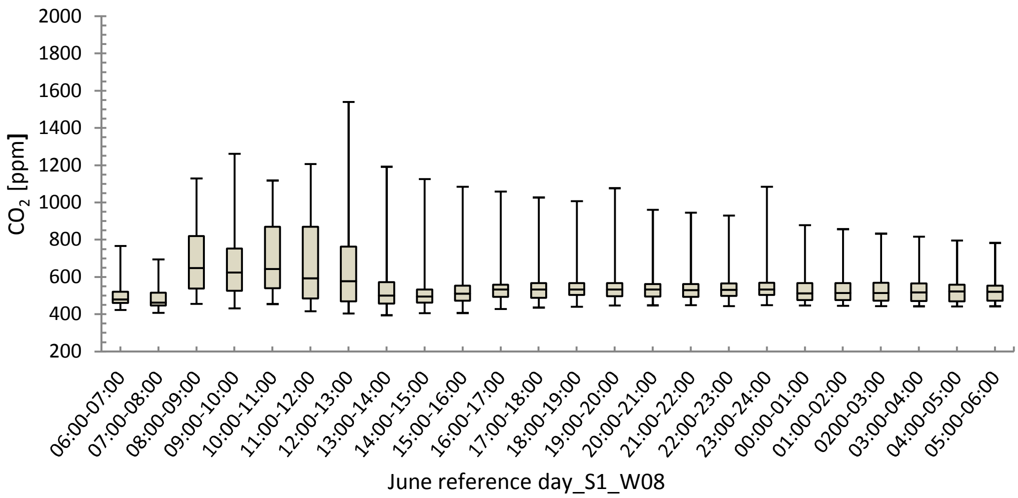

Figure 52: Boxplot of CO_2 level of a reference day in June of School 1 (W08)

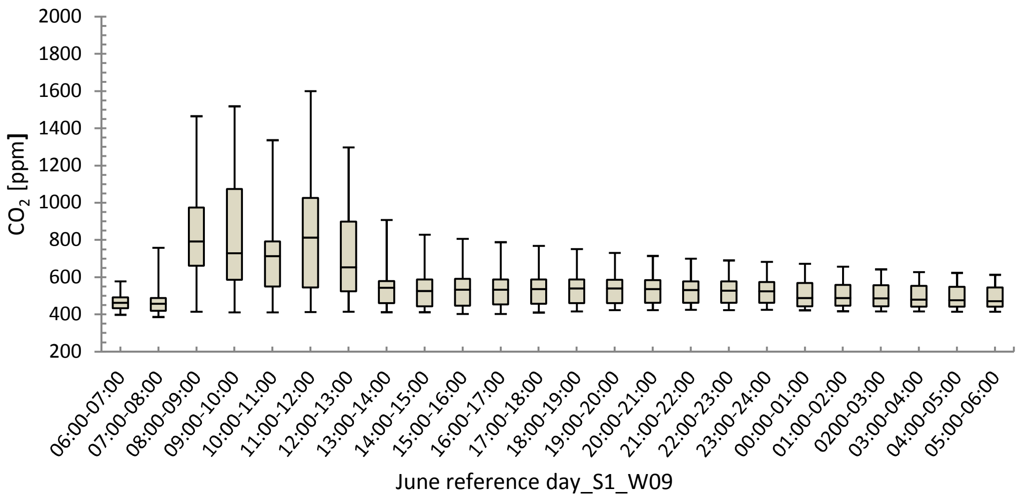

Figure 53: Boxplot of CO_2 level of a reference day in June of School 1 (W09)

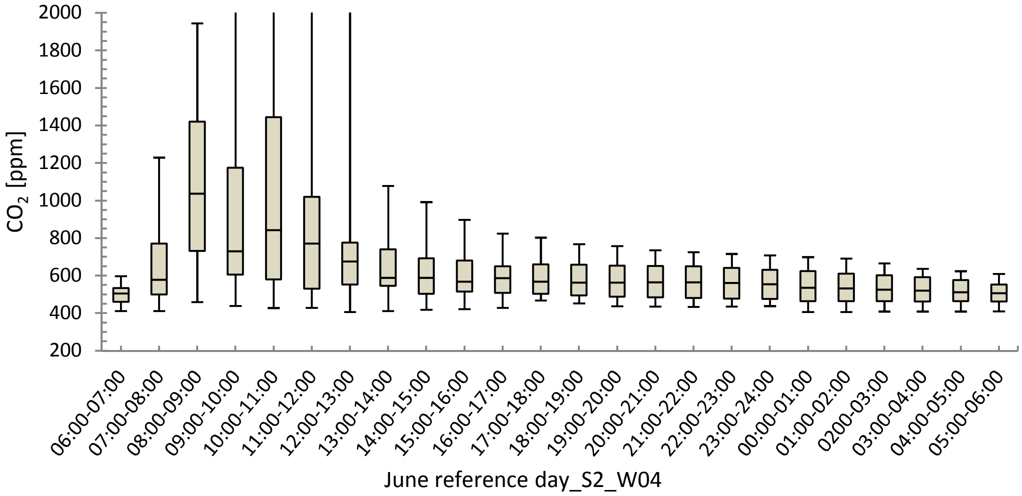

Figure 54: Boxplot of CO_2 level of a reference day in June of School 2 (W04)

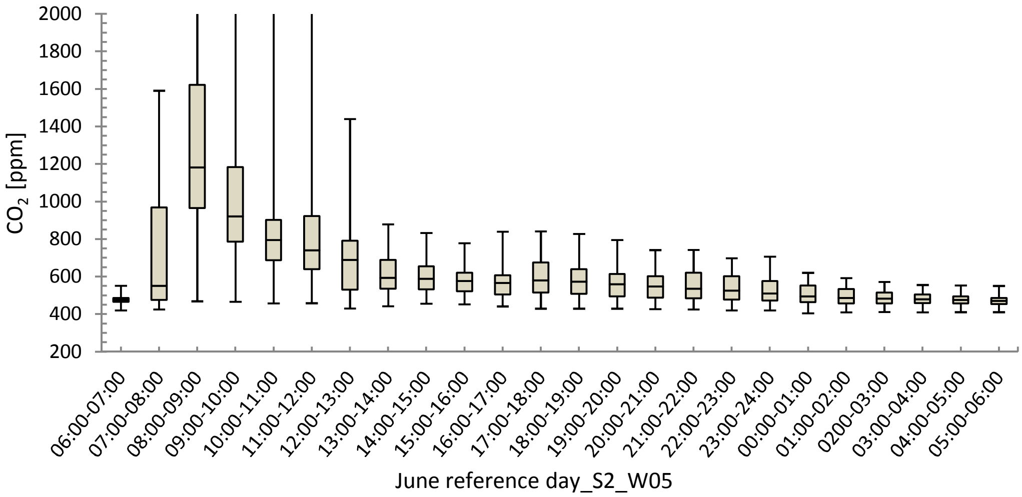

Figure 55: Boxplot of CO_2 level of a reference day in June of School 2 (W05)

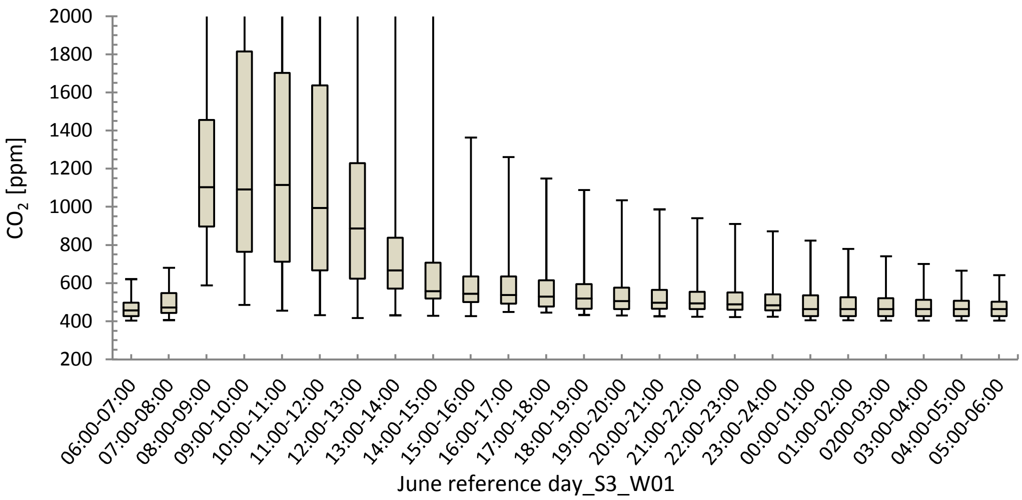

Figure 56: Boxplot of CO_2 level of a reference day in June of School 3 (W01)

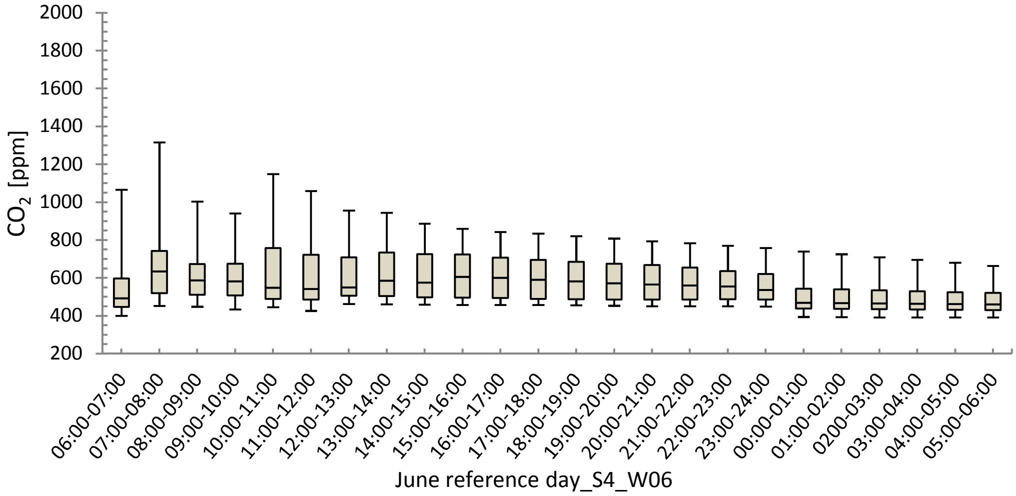

Figure 57: Boxplot of CO_2 level of a reference day in June of School 4 (W06)

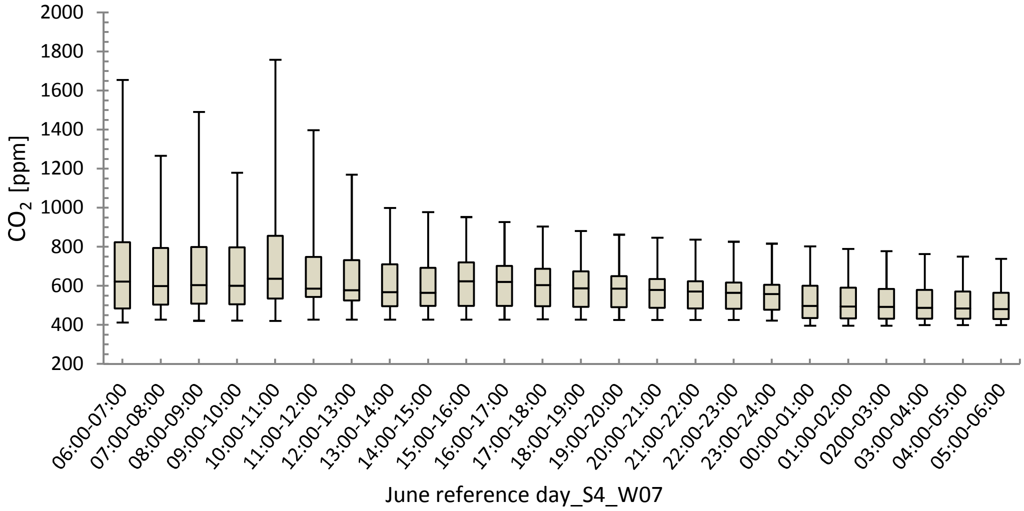

Figure 58: Boxplot of CO_2 level of a reference day in June of School 4 (W07)

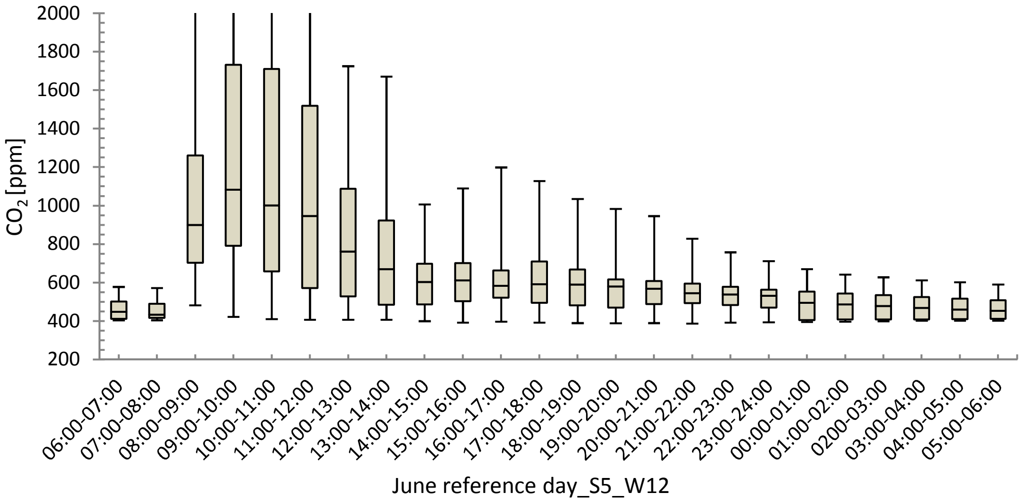

Figure 59: Boxplot of CO_2 level of a reference day in June of School 5 (W12)

S4 shows a constant good air quality in both graphs. Considering the CO_2 value gap between Q1 and Q3 (500 ppm-850 ppm), we can presume that the windows of these classes were most of the school time open (continuous airing).

A similar performance is also detected by W08 in S1, while W09 seems to be evidence for often shock ventilations when the peaks are about 1200-1400 ppm.

Also S2 classes seem to shock ventilate instead of leaving the windows open. But the users start the airing when values are already too high.

The two container schools S3 and S5 both show the most dispersion of values and often very high CO_2 concentrations of over 1000 ppm. This may be explained by the swift changes of internal factors in a container and its prompt reactions to the user behaviour and inside (or outside) temperatures due to its envelope.

Consequently the occupants may have let the windows for a longer time closed, especially in the cooler morning hours. In the following, a line graph of the medians in the June reference day, evidently demonstrates a poorer air quality of the container classes in this month.

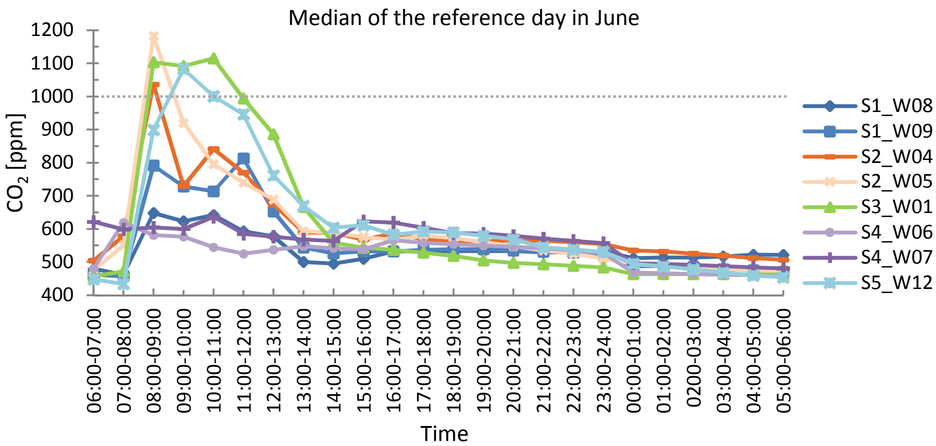

Figure 60: CO_2 median for a reference day in June

4.7. Psychrometric Charts

Temperatures and relative humidity of the schools in the opening hours (8:00-13:00) in the five month measurement period and the outdoor mean temperatures are utilized to derive the following results:

Two different methods of defining the comfort zones, provides us different results about the percentage of data points which are out of the comfort range, these methods are;

A: Using the outdoor mean temperature with the adaptive method (This method is only used for unconditioned spaces, therefore it can only be considered for the non heating period of this study)

B: Applying a given range according to ÖNORM (ÖNORM EN 7730, 2006)

Table 19 summarizes the monthly results (fraction of time outside comfort zone) for each school. Comparing these results using method A, the best values belong to S2 and S1. The poorest performance can be observed in the S4, which may be explained by the regulation problems of the heating system during the construction period of the school annex. As predicted, the two container schools were rather uncomfortable with data points lying out of the comfort zone for more than half of the considered period.

The worst results between all of the schools are seen in February in comparison to other measurement months with a mean of 91 % of the data point out of the comfort zone. This may lay on the suggested adaptive comfortable temperature values in this method, which in practice are probably higher than in the theory. Generally, all schools show a very poor performance using Method A, especially in the colder months (February and March).

Table 19: Percentage of out of range data points

	Schools (Method A)					Schools (Method B)				
Month/Schools	**S1**	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**
February	55.7	73.6	99.1	93.9	98.7	12.4	3.2	34.3	15.6	42.6
March	43.9	23.8	74.0	92.8	79.8	1.6	0.9	5.3	10.8	37.7
April	37.7	8.0	22.6	65.7	42.9	12.7	1.1	6.7	36.8	27.9
May	24.8	21.6	26.7	77.7	40.3	5.7	13.9	17.0	17.9	26.5
June	40.7	29.4	33.8	92.9	45.2	4.9	3.9	22.2	65.1	30.3
Whole period	40.6	31.3	51.2	84.6	61.4	7.5	4.6	17.1	29.2	33.0

Considering the ÖNORM range of thermal comfort, the results do look slightly better. In average the two container schools and the S4, which had heating regulation problems, show the least percentage of comfort. S5 has a constant percent of discomfort over the five month of the measurement time, especially in the colder month of February it has around 40% of the time too high temperatures. The best results are seen in S2 with 95.4 % of the time being the defined comfort zone of the ÖNORM (ÖNORM EN 7730, 2006).

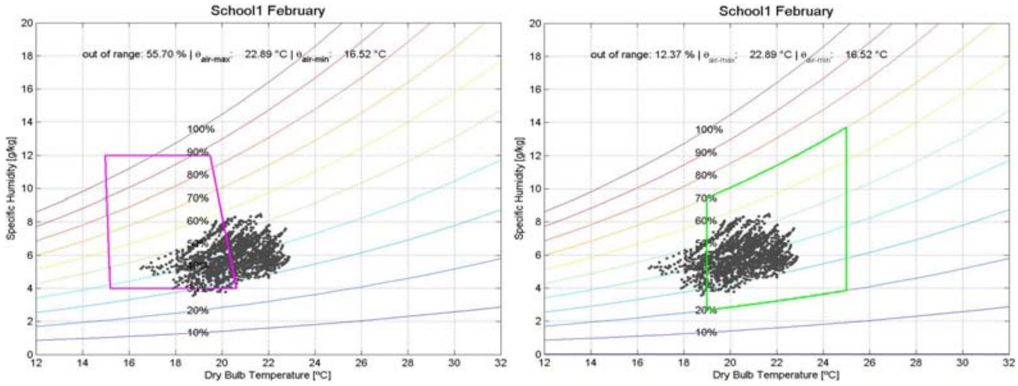

Figure 61: Psychrometric chart of S1 in February 2011 during school time

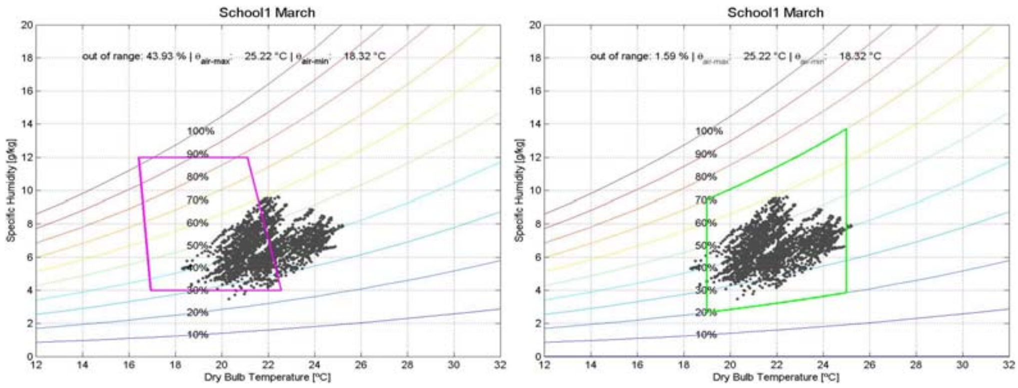

Figure 62: Psychrometric chart of S1 in March 2011 during school time

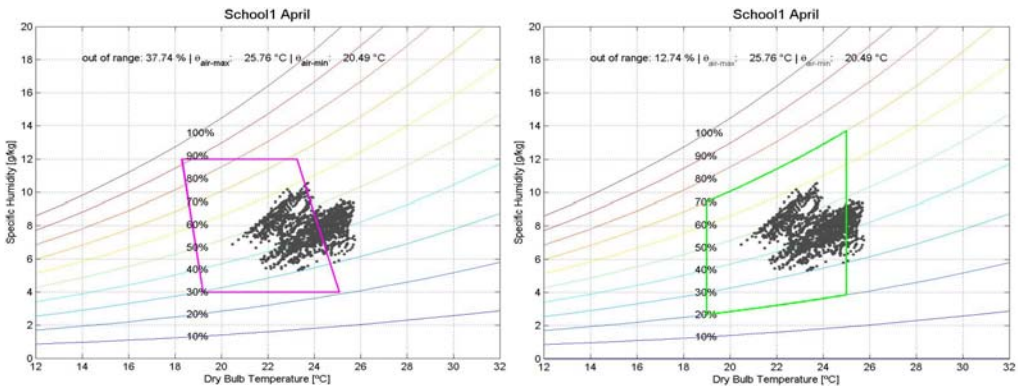

Figure 63: Psychrometric chart of S1 in April 2011 during school time

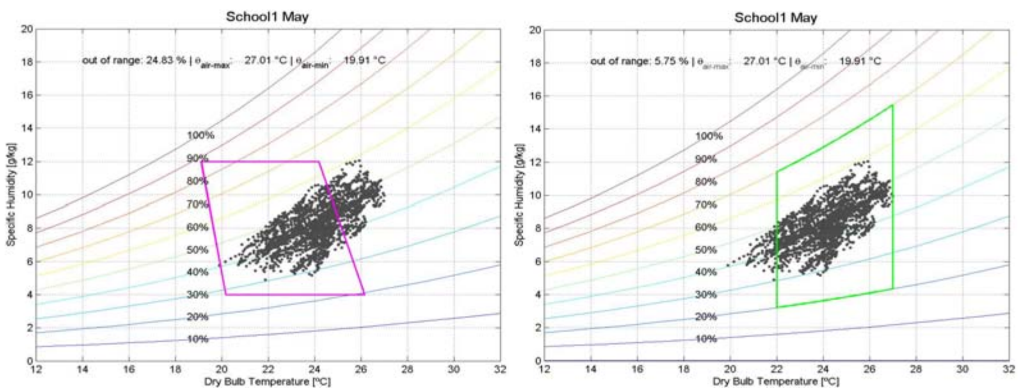

Figure 64: Psychrometric chart of S1 in May 2011 during school time

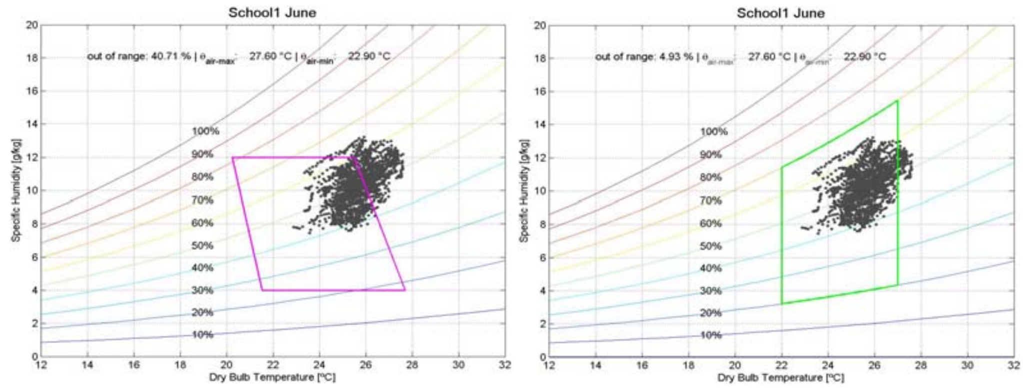

Figure 65: Psychrometric chart of S1 in June 2011 during school time

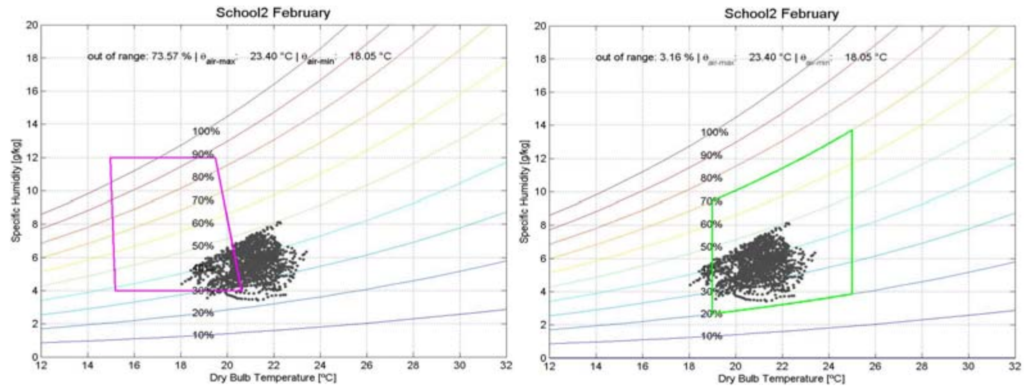

Figure 66: Psychrometric chart of S2 in February 2011 during school time

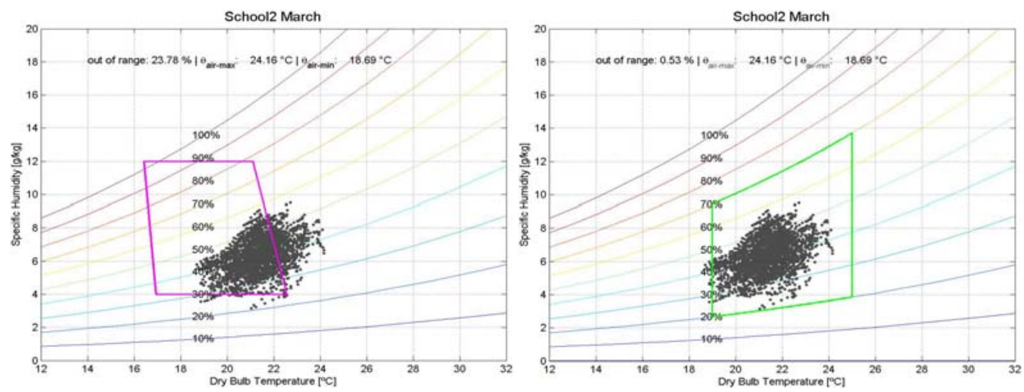

Figure 67: Psychrometric chart of S2 in March 2011 during school time

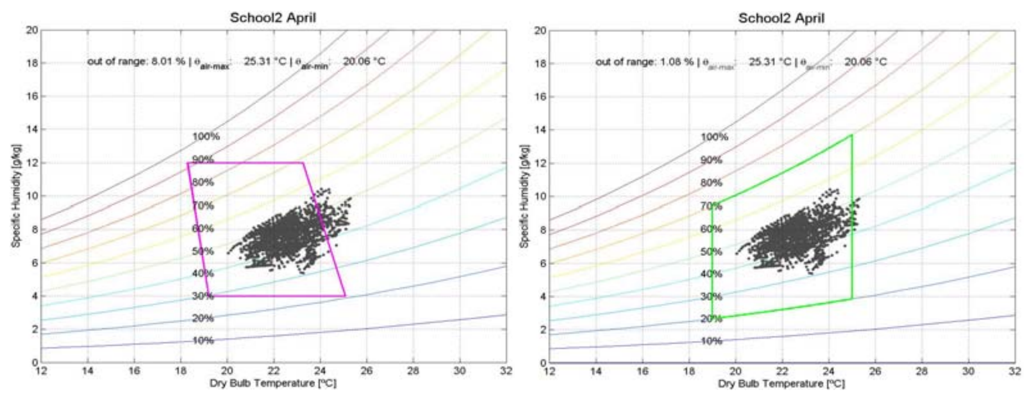

Figure 68: Psychrometric chart of S2 in April 2011 during school time

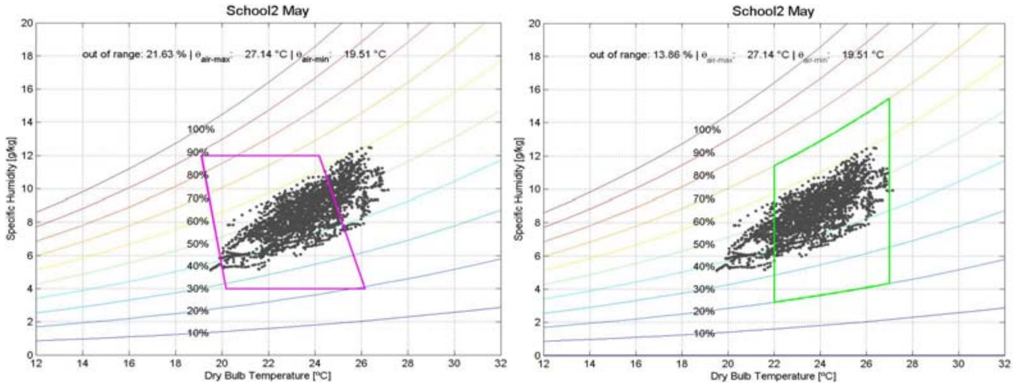

Figure 69: Psychrometric chart of S2 in May 2011 during school time

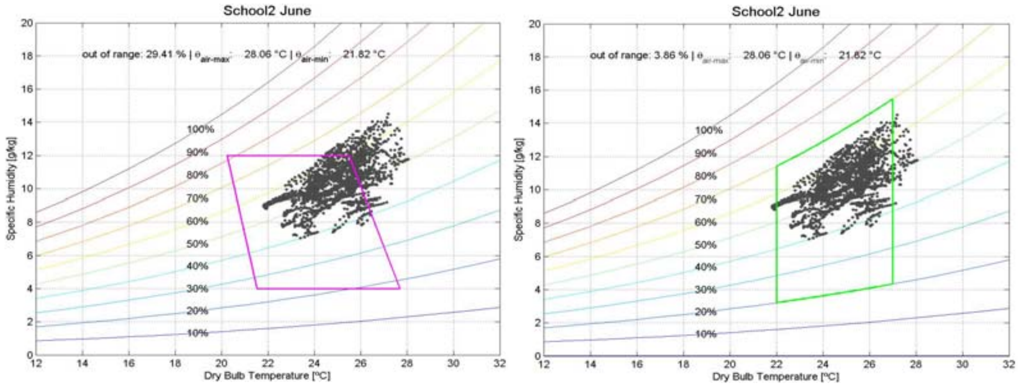

Figure 70: Psychrometric chart of S2 in June 2011 during school time

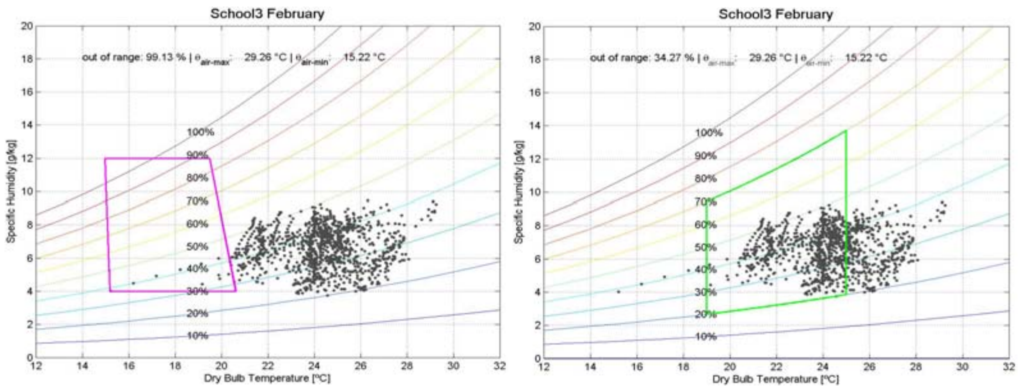

Figure 71: Psychrometric chart of S3 in February 2011 during school time

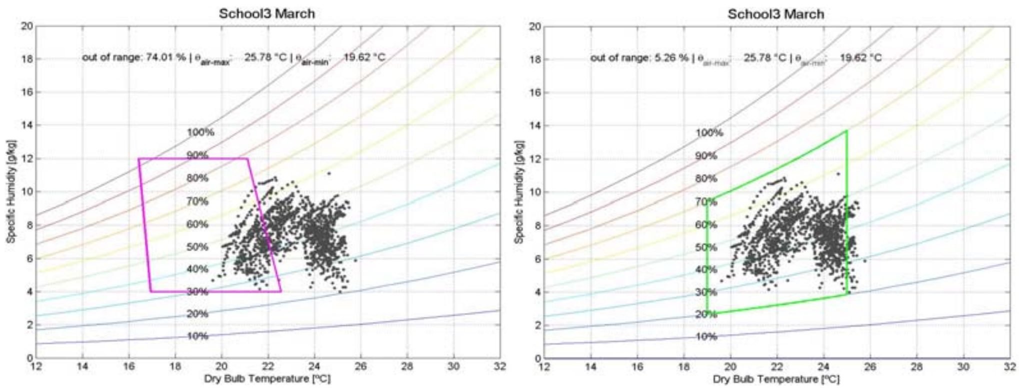

Figure 72: Psychrometric chart of S3 in March 2011 during school time

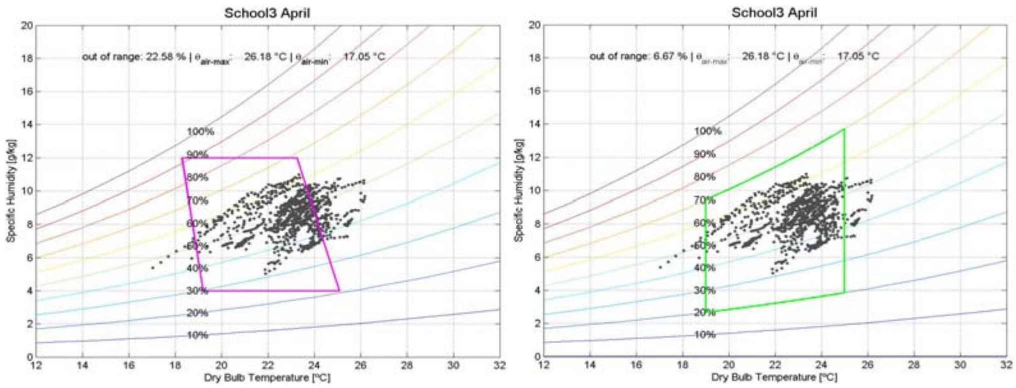

Figure 73: Psychrometric chart of S3 in April 2011 during school time

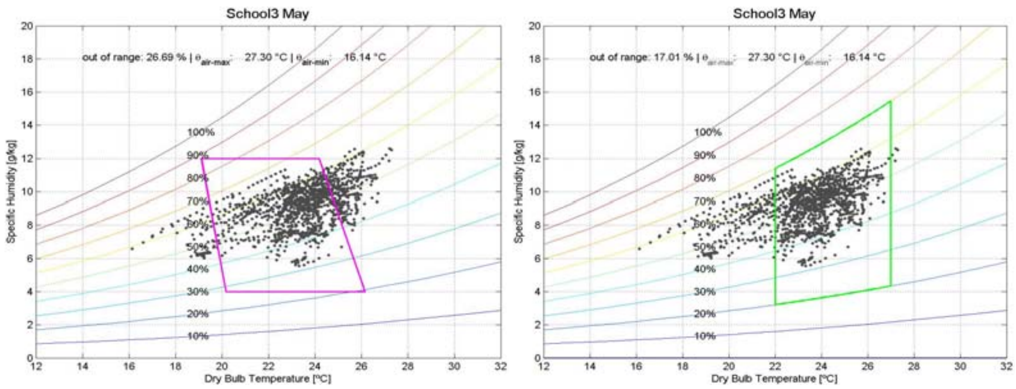

Figure 74: Psychrometric chart of S3 in May 2011 during school time

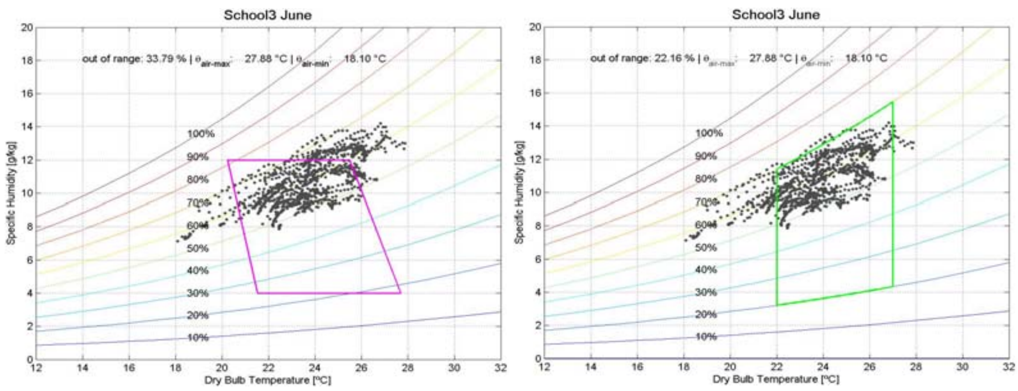

Figure 75: Psychrometric chart of S3 in June 2011 during school time

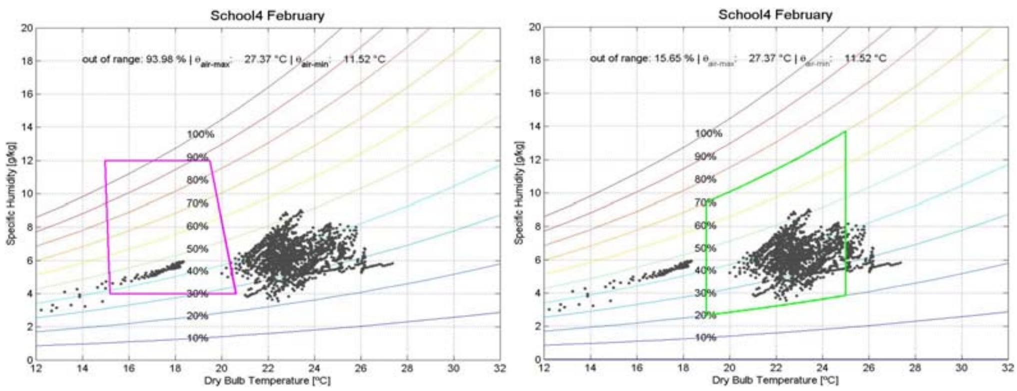

Figure 76: Psychrometric chart of S4 in February 2011 during school time

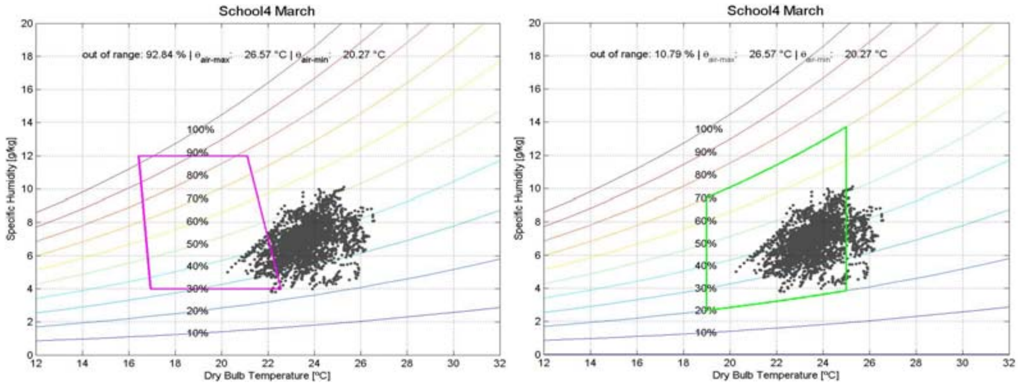

Figure 77: Psychrometric chart of S4 in March 2011 during school time

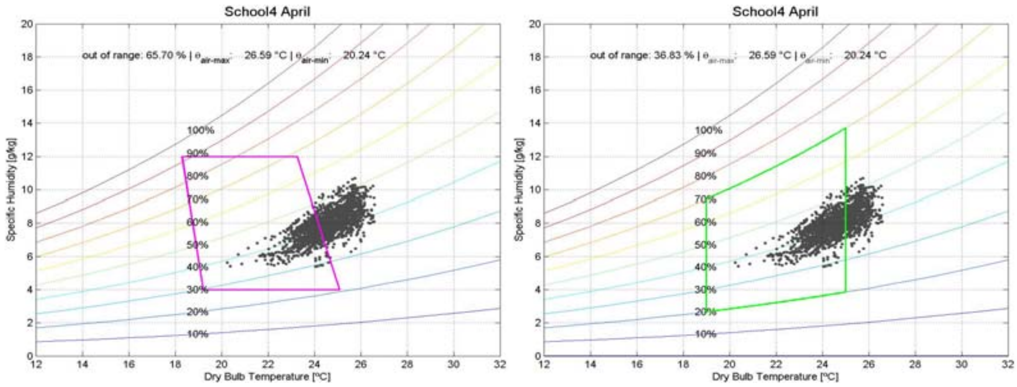

Figure 78: Psychrometric chart of S4 in April 2011 during school time

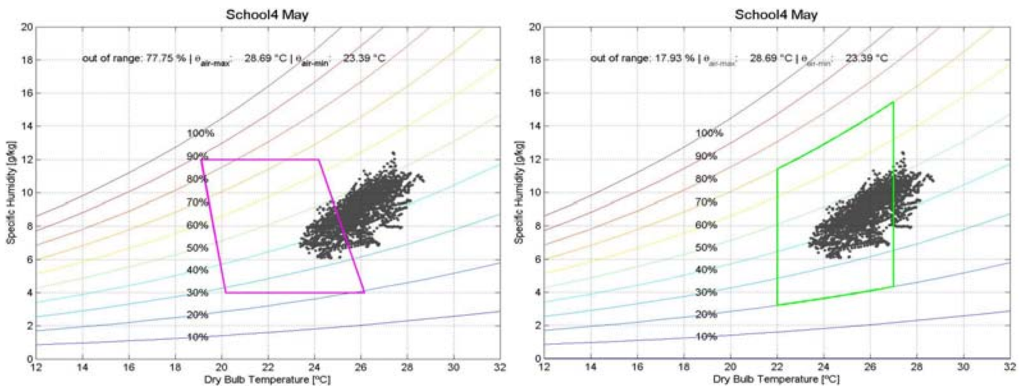

Figure 79: Psychrometric chart of S4 in May 2011 during school time

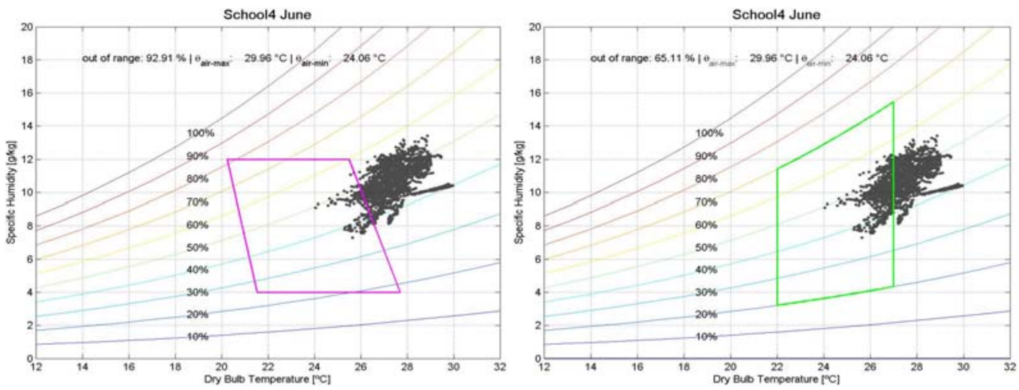

Figure 80: Psychrometric chart of S4 in June 2011 during school time

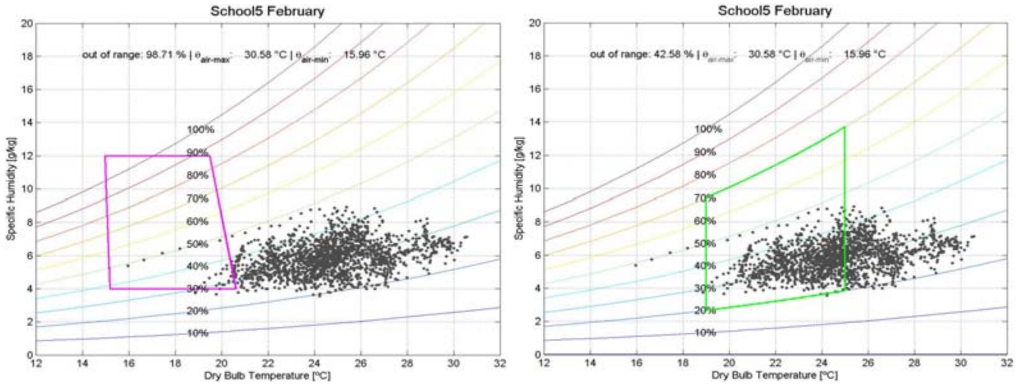

Figure 81: Psychrometric chart of S5 in February 2011 during school time

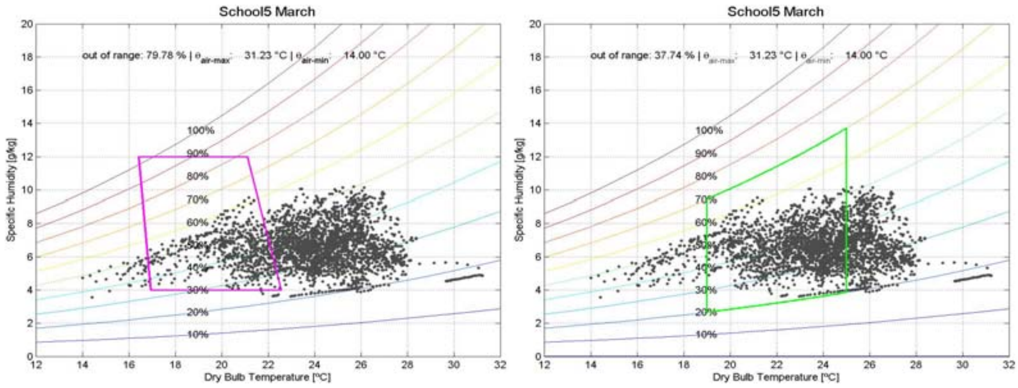

Figure 82: Psychrometric chart of S5 in March 2011 during school time

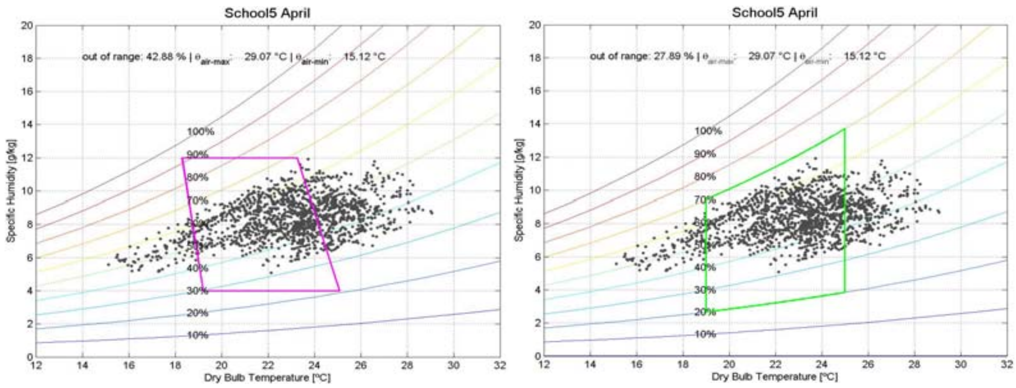

Figure 83: Psychrometric chart of S5 in April 2011 during school time

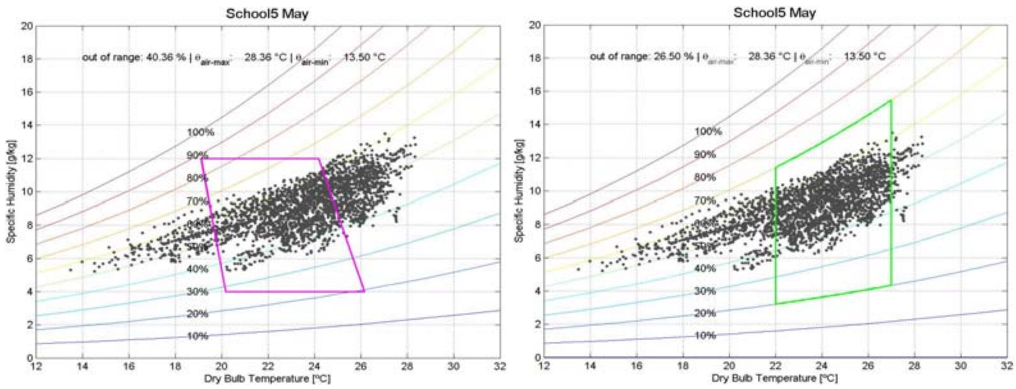

Figure 84: Psychrometric chart of S5 in May 2011 during school time

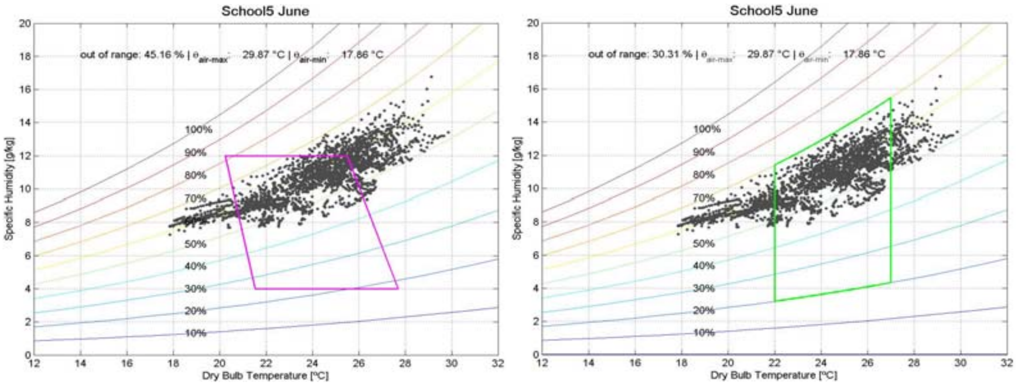

Figure 85: Psychrometric chart of S5 in June 2011 during school time

4.8. User Evaluation

In the following sections, the results of the filled questionnaires are presented. The teachers of the two container schools and two of the normal schools filled the questionnaires which can be found in the appendix. The results have been exposed in graphs for easy evaluation.

4.8.1. Day light situation

In question 7 the teachers were inquired about the daylight situation of their classrooms. The results are shown in Figure 86 .

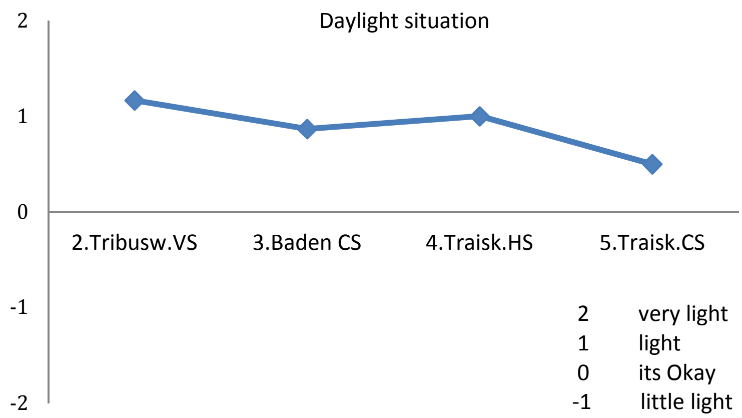

Figure 86: Daylight situation

It seems that the container classes were not as bright as the normal schools which can be explained by being placed lower than most of the classes of the normal schools. These schools were just one or two stories and had less height than the older buildings (2.25 meters). It is understandable that they are also perceived darker by the occupants.

4.8.2. Disturbance due to direct sunlight

In question 8 the teachers were inquired to rate the disturbance due to direct sunlight. The S3 and S2 seem to have sometimes problems with the direct sunshine.

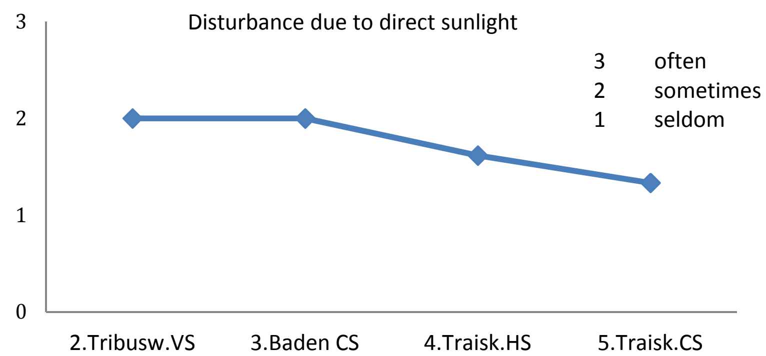

Figure 87: Disturbance due to direct sunlight

4.8.3. **Satisfaction with the heating**

In question 12 the teachers were inquired to rate the satisfaction with the heating in the classrooms. As it seems only in S3 the teachers found the heating was acceptable, and in S5 they were least satisfied with the heating.

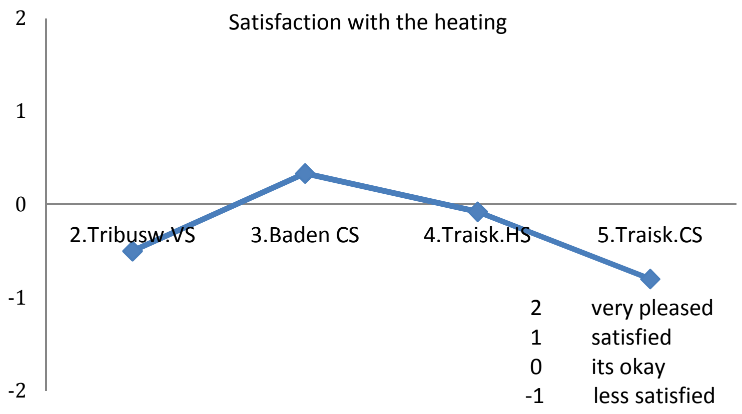

Figure 88: Satisfaction with the heating

4.8.4. **Air quality in winter**

In question 14 the teachers were inquired to rate the air quality of the classroom in the cold period of the year. The schools were all manually ventilated.

It seems that the teachers in S3 (and S5) did not ventilate as much as other schoolteachers and found that the air had a bad quality. This was also noticeable in the measurement results.

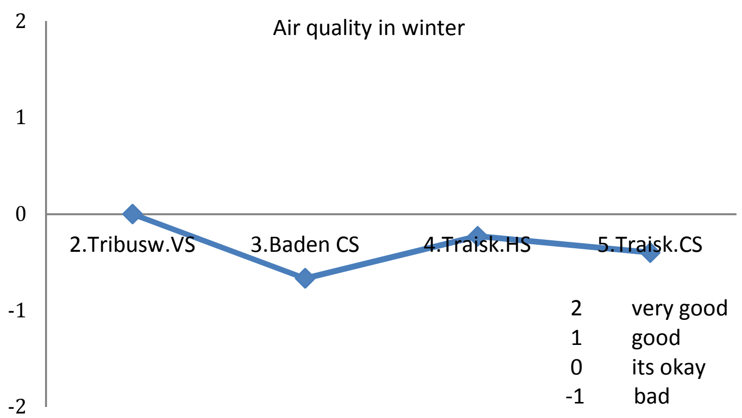

Figure 89: Air quality in winter

4.8.5. **Room temperatures in winter**

In question 15 the teachers were inquired to rate the winter temperatures. The teachers in S2 seem to have problems with the cool temperature in winter season. As we could see from the results, this school (S2) has often the coolest temperatures among the other schools; however they were always laying in the suggested ranges of ÖNORM. While the other schools and especially S3 and S5 had often too high temperatures for the winter season.

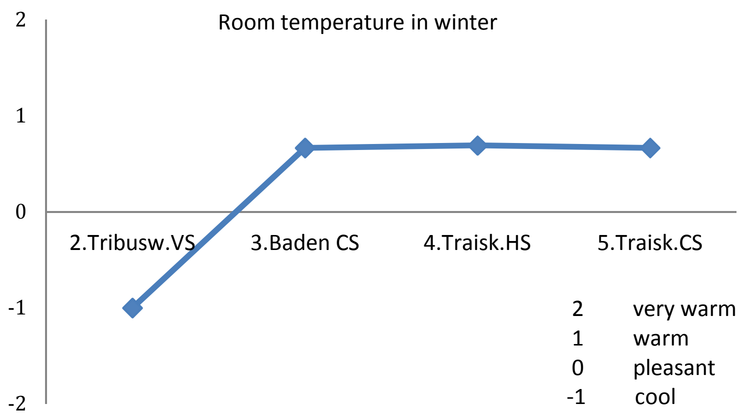

Figure 90: Room temperature in winter

4.8.6. **Humidity in winter**

In question 16, the teachers were inquired to rate the humidity of their classrooms in winter. It seems that in all schools, the air in the classrooms was perceived as dry to very dry. The container school S3 had the driest air in winter as it can see in Figure 91.

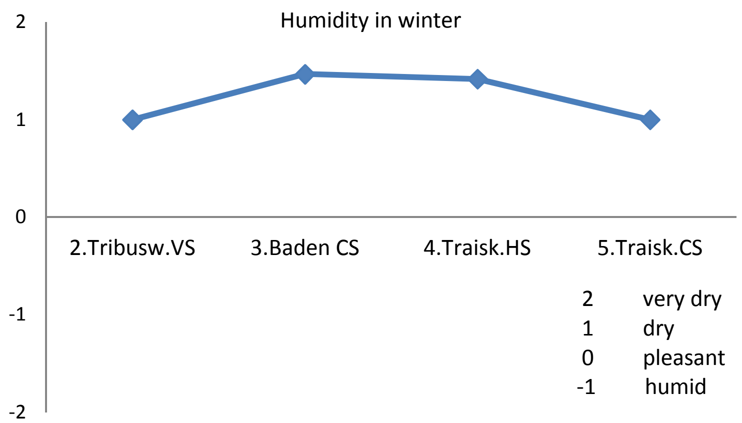

Figure 91: Humidity in winter

4.8.7. Thermal comfort of the classroom

In question 17 the teachers were inquired to rate the general thermal comfort of their classrooms. It seems that even though in comparison to the other schools, the temperatures in S2 were perceived as cool; still the occupants felt that the classrooms were generally comfortable.

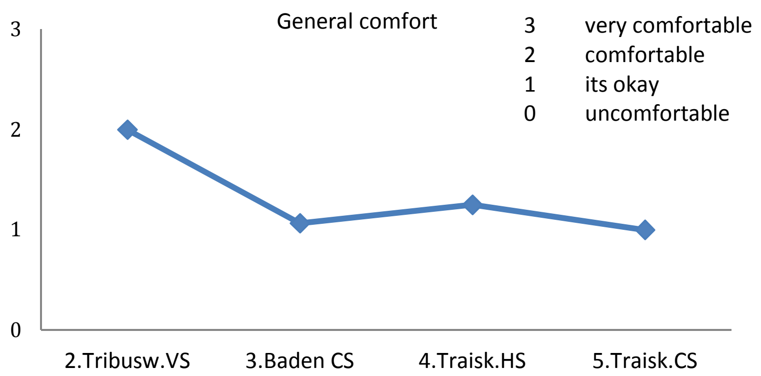

Figure 92: general comfort

4.8.8. Health problems

In question 20, the teachers were inquired to describe their health problems, dwelling in the classrooms. It is clear that the container class-occupants (teachers) had the highest health problems listed in the questionnaires.

Headache, weariness, respiratory complaint and nose irritations are all signs of an unhealthy and dry air quality of the classes. As we could also observe in the relative humidity results in February this was also confirmed.

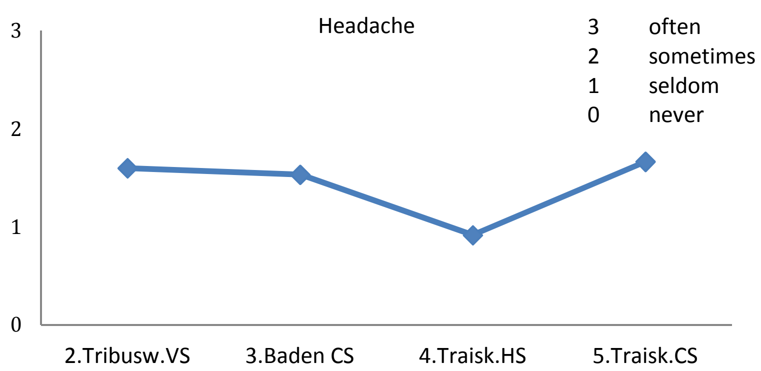

Figure 93: Headache

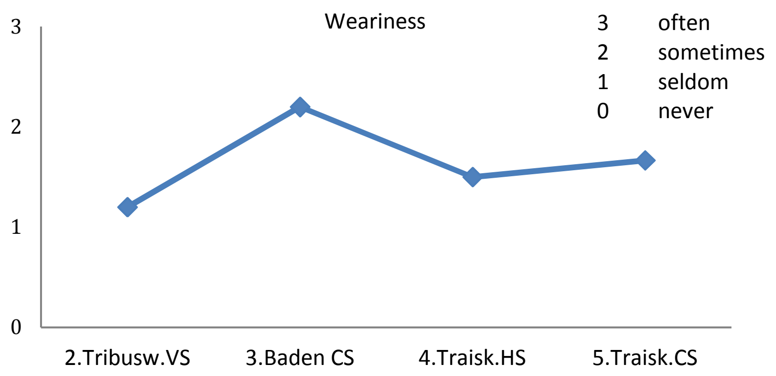

Figure 94: Weariness

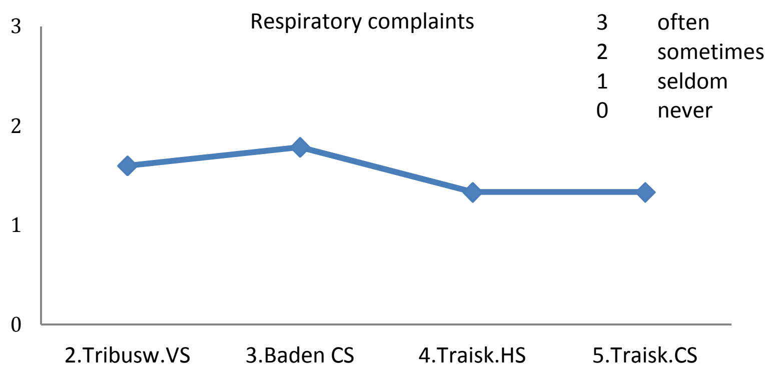

Figure 95: Respiratory complaints

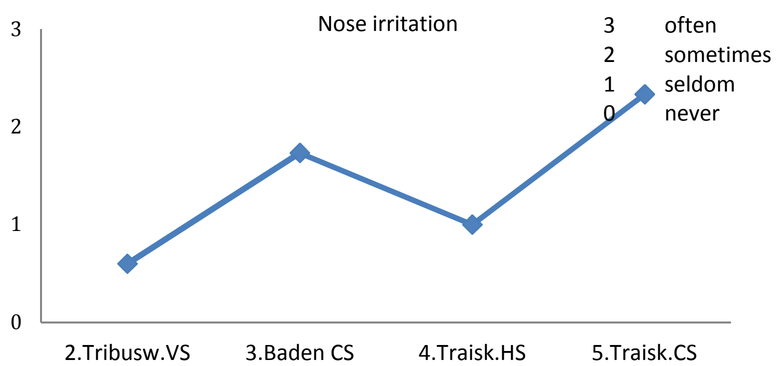

Figure 96: Nose irritation

4.9. **Brief Discussion**

During the heating season in February the temperatures of the two container schools S3 and S5, were about 40% of the time, higher than the 25°C defined by ÖNORM for this period of the year. As the overheating may have resulted from a high difference between the radiant temperature of the enveloping surfaces and the air temperature of the classes in the container schools, this was studied in Sections 4.3.1 and 4.3.2 and resulted in a radiant temperature difference of maximum 1.15 °C which is less than 2-3 °C and adequate to feel comfortable.

It may be the psychological consequence of the rather dark classrooms (which can be seen from the assembled data in the questionnaires shown in Section 4.8.1), which makes the occupants feel cold and consequently overheat the classes.

It was unexpected to observe a constant dropping of the temperature in S5 (during February), while all other schools had a rising temperature in the opening hours of the schools due to internal gains, rising outside temperatures and the solar gains. This monotonic decrease of the temperature that was observed (see appendix, Section 8.4) in February may have been resulted from regular half-opened windows.

In February the humidity of S5 has been low (50 % of the time below 30% RH). Considering the absolute humidity values in comparison to the other classes, most likely the dryness of the classes in this school was causing the health problems of the occupants of the classes as mentioned in the questionnaire (4.8.8).

The same problem is also noticed in S3, with the distinction that the humidity values, particularly the absolute humidity, was rather the highest among all the schools, which also may not be that comfortable considering the temperatures and may be the cause of tiredness for some teachers as one can see in Figure 94 (Weariness).

In the rest of the measurement period the measurements (during March and April) both showed more or less the same results; the classrooms of S3 and S5 were still slightly over heated (S5 more so with 34% of the time in March over 25°C) but not as much as in February.

There was a general shift in temperatures of the container schools to rather lower temperatures during the measurement period observed for instance in April 8% of the time S5 had lower temperatures than 19°C. In June 23% in S5 and in S3 19% cooler temperatures than 22°C (which is the benchmark for the non-heating season) were noted.

The relative humidity values in these months were more or less all up to standard and did show a predicted performance. In June, high percentages of absolute humidity may have resulted, moist and uncomfortable air, especially in S5 which had 32.5% of the time absolute humidity values of more than 14 g/m³ (see 4.5).

In June, the CO_2 values were also evaluated and the results show that both container schools do have higher concentrations of Carbon dioxide than the other schools, which may have been resulted from the non existing possibility of cross ventilation in these schools. Alternatively the occupants might think that often airing of the classes may cause a temperature drop, stronger than in the normal schools. This may be the same reason for overheating the classes in the winter season.

5. CONCLUSIONS

5.1. Main Contribution

A comparison of normal schools and container schools in Baden was performed. This was partially based on monitored indoor environmental conditions including dry bulb temperature, relative humidity and CO_2 concentration values in addition to calculated data such as absolute humidity and radiant and operative temperatures. A user evaluation was also part of assembling the empirical data.

In order to gain an objective assessment of the indoor environmental conditions of the schools, about 430,000 data points were acquired and processed during five months, from February to June 2011.

During the heating season, an excessive heating of the container schools was observed, which resulted in wasted energy and higher heating costs, especially considering the high price of electric heating.

In general the normal (non-container) schools had all acceptable temperature values other than in the morning hours, when the heating system still had not managed to warm up the air to the standard temperature of 22 °C.

These findings are made apparent through psychrometric charts (Section 4.7) and the percentages of data points which lay out of the range specified by ÖNORM.

Considering the absolute humidity and CO2 values in June it can also be seen that the ventilation of the schools, and the container-based schools in particular, was not been as effective as it should have been.

5.2. Further Research

Future studies can focus on a more precise user behaviour investigation in the classes and also how this can be affected by the three values of temperature, relative humidity, and CO_2 concentration in each classroom. Such studies would uncover the reason why container classrooms were overheated during the winter season.

It would also be helpful to acquire data on CO_2 concentrations over the entire winter season and compare the data with changes of temperature and relative humidity and discover correlations between them.

Considering our findings, we strongly suggest that a CO_2 alarm be installed in container-based classrooms so that the users know when they need cross ventilation. How to cross ventilate best in the container classes is also an issue which needs to be investigated.

With regards to the economics of container-based classrooms, a comparison of energy consumption to normal classrooms can help us define cost-cutting methods for affected schools, even when containers are used only as a short-term solution.

Electric heating is characterized as being a very speedy heating method, and in order to maximize the gains of such a system in container classrooms, it would be beneficial to start the heating in the early morning hours based on outdoor temperatures and occupation and to prevent unnecessary heating at night and on weekends.

It seems to be also necessary to reconsider the fixed timing method of heating of even in non-container based schools during the cold season (i.e. starting heaters 5:00 in the morning every day).

A technological solution that takes outside temperatures may be needed to control indoor temperatures, so that in the morning hours, when the pupils attend classes, the ÖNORM defined values can be attained.

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7. CAPTIONS

7.1. Tables

7.2. Figures

8. Appendix

8.1. Questionnaire

Sehr geehrte Lehrerin! Sehr geehrter Lehrer!

Herzlichen Dank im Voraus, dass Sie sich für die Beantwortung der nachfolgenden Fragen Zeit nehmen. Dieser Fragebogen ist Teil meiner Diplomarbeit, die ich an der Technischen Universität Wien/Institut für Bauphysik und Bauökologie verfasse. Ich bitte Sie um möglichst offene und genaue Angaben – schwerpunktmäßig bezogen auf die vergangenen Wintermonate. Um absolute Vertraulichkeit zu gewährleisten, geben Sie bitte den ausgefüllten Fragebogen verschlossen im beigelegten Kuvert in der Direktion ab.

Interne Kondition der Klassenzimmer

1. Klassenzimmer _______________

2. Ihr Geschlecht: ❑ männlich ❑weiblich

3. Ihr Alter: ❑25- 35 ❑35-45 ❑45-55 ❑55-65 ❑über 65

4. Wie lange arbeiten Sie schon in diesem Klassenzimmer? _______ Jahre und _______ Monate

5. Wie viele Schüler haben Sie im 2010-11 in der Klasse betreut? WS 2010 ______ Schüler

   SS 2011 ______ Schüler

6. Wie viele Unterrichtsstunden verbringen Sie durchschnittlich täglich in ihrem Klassenzimmer? _______ Std.

7. Wie ist im Klassenzimmer die Tageslichtsituation?

   ❑sehr viel Licht ❑viel Licht ❑es geht ❑wenig Licht ❑sehr wenig Licht

8. Werden Sie durch direktes Sonnenlicht gestört? ❑häufig ❑gelegentlich ❑selten ❑nie

9. Ist in der Klasse ein Sonnenschutz vorhanden? ❑ ja ❑ nein Welcher? ____________________

10. Wie lange ist durchschnittlich im Winter tagsüber die künstliche Beleuchtung eingeschaltet? ____Std.

11. Werden Sie in Ihrer Klasse durch Lärm von außen gestört? ❑ ja ❑ nein

    Wenn ja welche Quellen sind das?

    ❑Gang ❑Nebenklassen ❑Verkehr /Straße Sonstige ____________________________

12. Wie zufrieden sind Sie mit der Heizung in Ihrem Klassenzimmer?

❑ sehr zufrieden ❑ zufrieden ❑ geht so ❑ weniger zufrieden ❑ gar nicht zufrieden

13. Wie (oft) lüften Sie Ihr Klassenzimmer im Winter?

❑ Gekipptes Fenster: ______ mal ____ min ❑ Stoßlüftung: ______ mal ____ min

14. Wie würden Sie die Luftqualität in der Klasse im Winter beurteilen?

❑ sehr gut ❑gut ❑ geht so ❑ schlecht ❑ sehr schlecht

15. Wie empfinden Sie im Durchschnitt im Winter die Raumtemperatur?

❑kalt ❑ kühl ❑ angenehm ❑ warm ❑ sehr warm

16. Beurteilen Sie nach Ihrem Gefühl die Raumfeuchte im Winter:

❑sehr feucht ❑eher feucht ❑angenehm ❑ trocken ❑sehr trocken

17. Fühlen Sie sich in dem Klassenzimmer generell wohl?

❑sehr wohl ❑wohl ❑geht so ❑weniger wohl

18. Wie viele PCs sind im Klassenzimmer eingeschaltet? _____PCs

19. Wie lange sind die PCs üblicherweise eingeschaltet? _____Std.

20. Leiden Sie unter Beschwerden nachfolgender Art?

	häufig	manchmal	selten	nie
Kopfweh				
Allg. Müdigkeit				
Probleme mit den Atemwegen				
Irritationen der Nase				
Sonstiges:………………………				

21. Haben Sie Änderungsvorschläge die zur Verbesserung der Innenraum Konditionen während der kalten Jahreszeit beitragen könnten?

Es bedankt sich nochmals,

Mit freundlichen Grüßen
Ihre DI. Parisa Kaveh

8.2. School profiles

S1: Elementary School Traiskirchen

Volksschule Traiskirchen	
construction year	1904
refurbishment time	2002-2005
refurbishment measures	exterior/classes remodelled
school hours	
class orientation	southeast-northwest
number of classes	17 classes
pupils per class	20- 25 pupils

S2: Elementary School Tribuswinkel

Volksschule Tribuswinkel	
construction year	1970 (annex 2009)
refurbishment time	2003-2004/2010
refurbishment measures	
school hours	7:25- 16:30
class orientation	south
number of classes	6 classes
pupils per class	20- 25 Pupils

S3: Elementary School Baden

Volksschule Baden (Containerschool)	
construction year	2010
built up for	2010-12
refurbishment measures	-
school hours	8:00-13:35
class orientation	northwest- southeeast
number of classes	17 classes
pupils per class	20- 25 Pupils

S4: Secondary School Traiskirchen

Hauptschule Traiskirchen	
construction year	1970
refurbishment time	2009-11
refurbishment measures	exterior
school hours	7:50-13 (15:55)
class orientation	south and east
number of classes	8 classes
pupils per class	20- 25 Pupils

S5: Secondary School Traiskirchen (Container)

Hauptschule Traiskirchen (Containerclasses)	
construction year	2004
built up for	2009-11
refurbishment measures	
school hours	7:50-13 (15:55)
class orientation	
number of classes	8 classes
pupils per class	20- 25 Pupils

8.3. Cumulative Frequency Graphs of Temperature and Relative Humidity

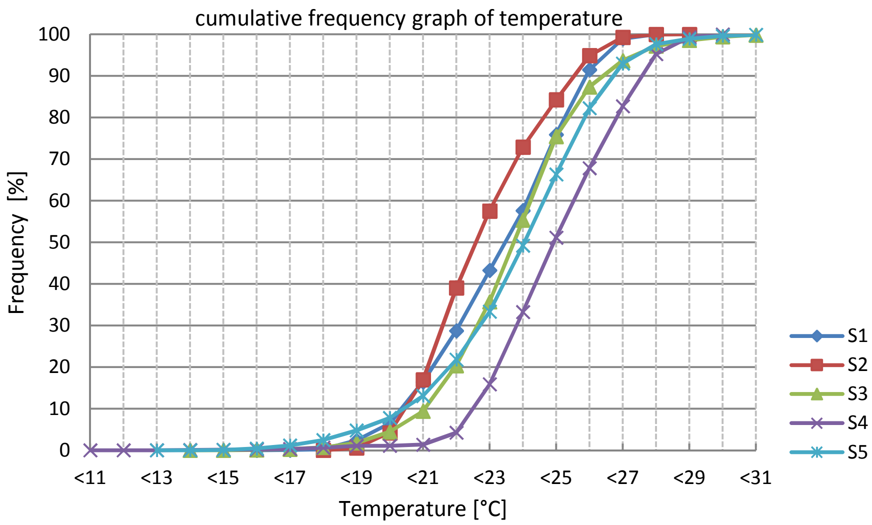


Figure 97: Cumulative frequency graph of temperature in all 5 schools

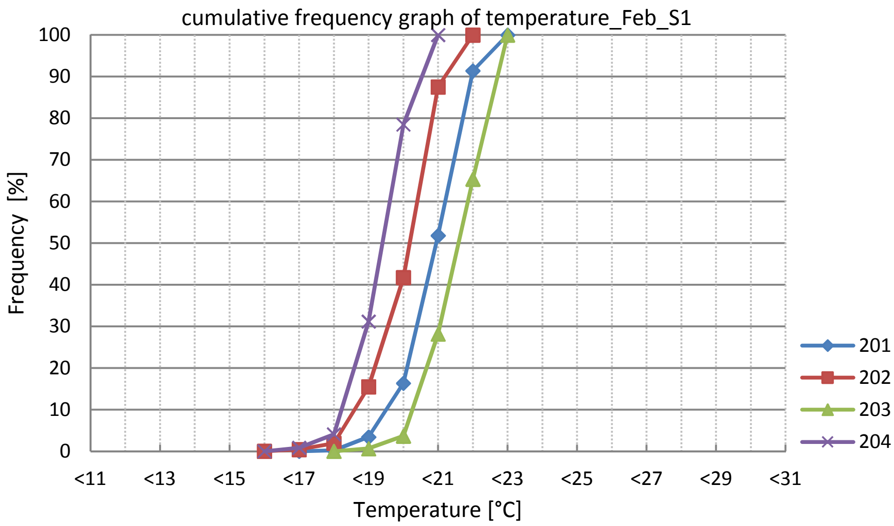


Figure 98: Cumulative frequency graph of temperature of S1 in February 2011

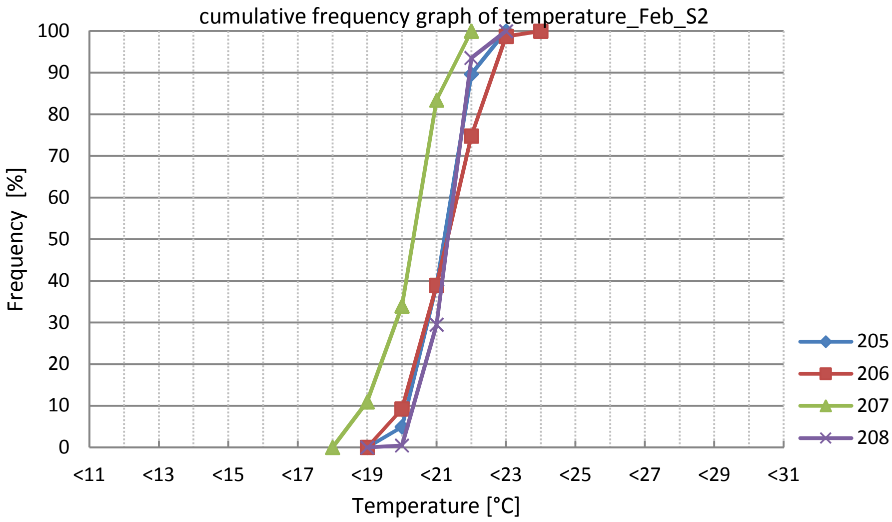


Figure 99: Cumulative frequency graph of temperature of S2 in February 2011

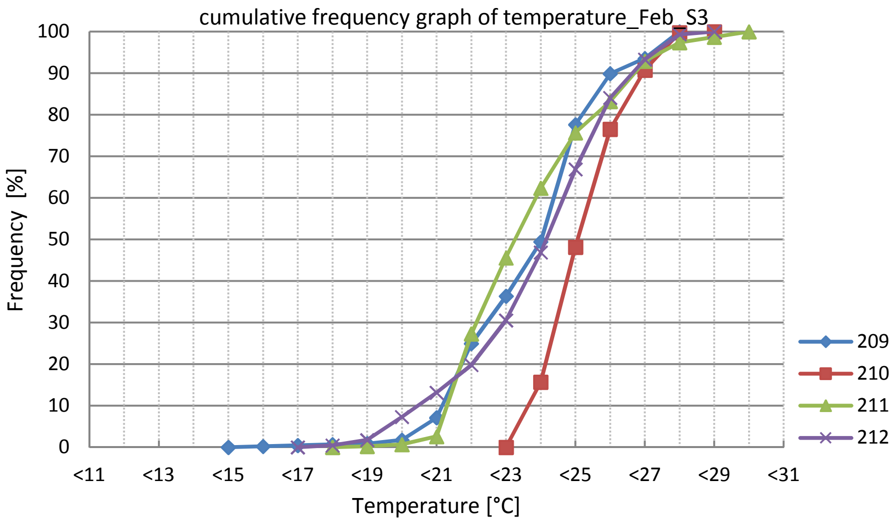


Figure 100: Cumulative frequency graph of temperature of S3 in February 2011

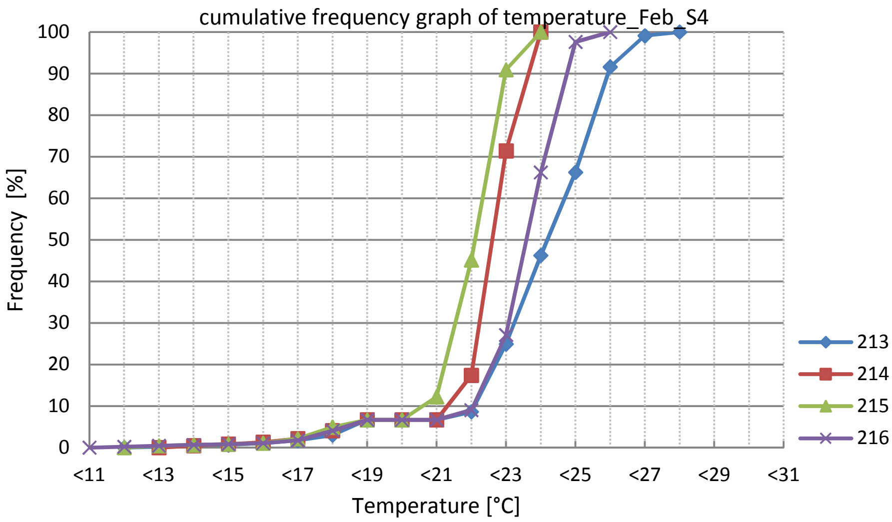


Figure 101: Cumulative frequency graph of temperature of S4 in February 2011

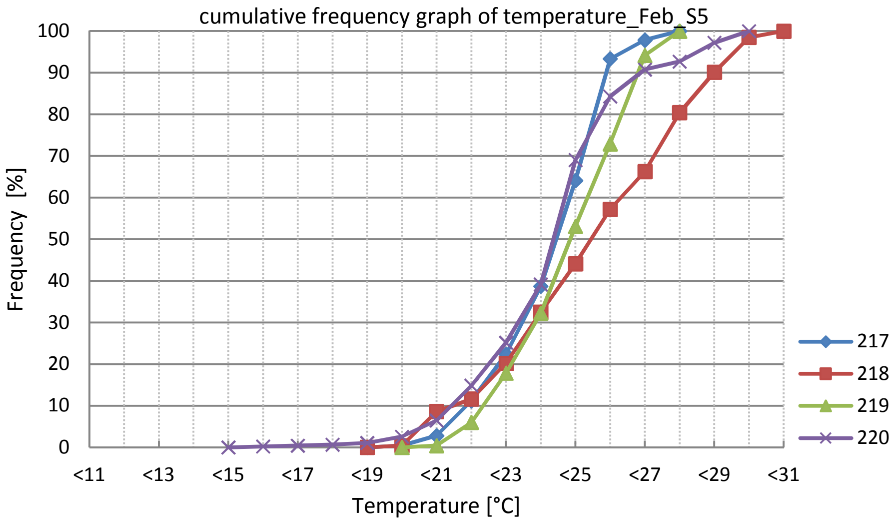


Figure 102: Cumulative frequency graph of temperature of S5 in February 2011

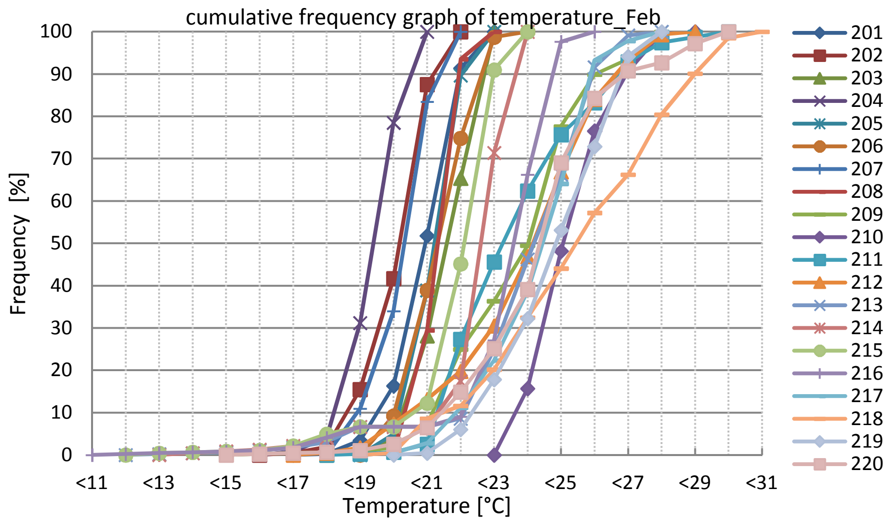


Figure 103: Cumulative freq. graph of temp. in February 2011 in all 20 classes during school time

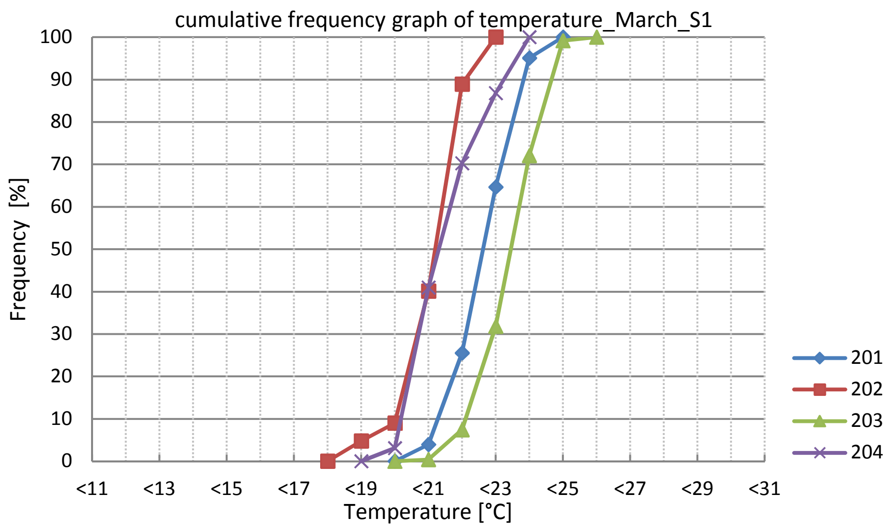


Figure 104: Cumulative frequency graph of temperature of S1 in March 2011

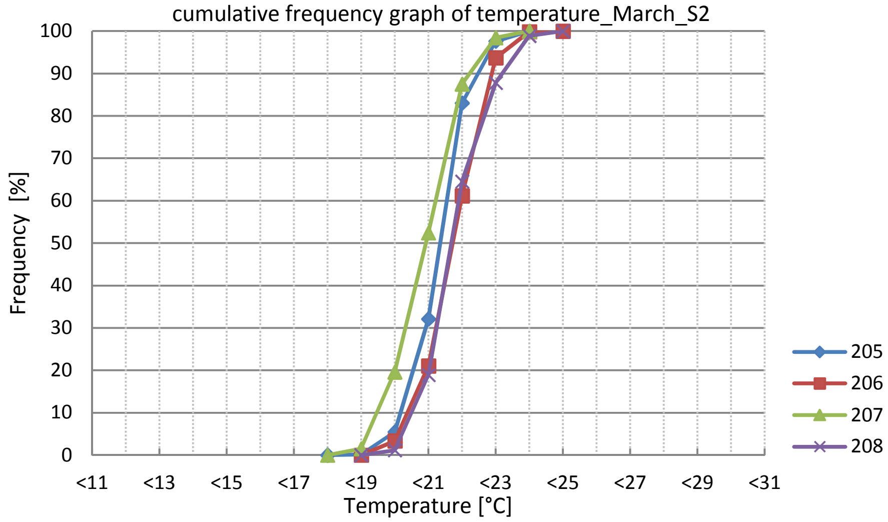


Figure 105: Cumulative frequency graph of temperature of S2 in March 2011

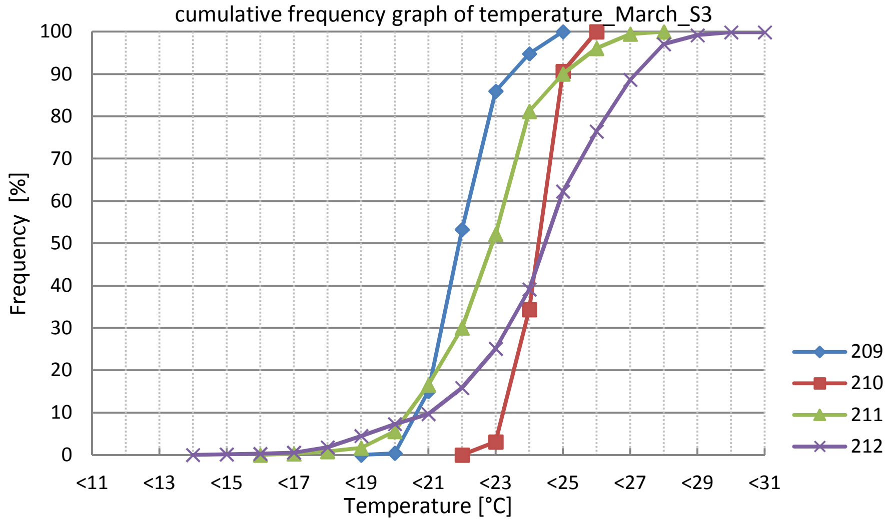


Figure 106: Cumulative frequency graph of temperature of S3 in March 2011

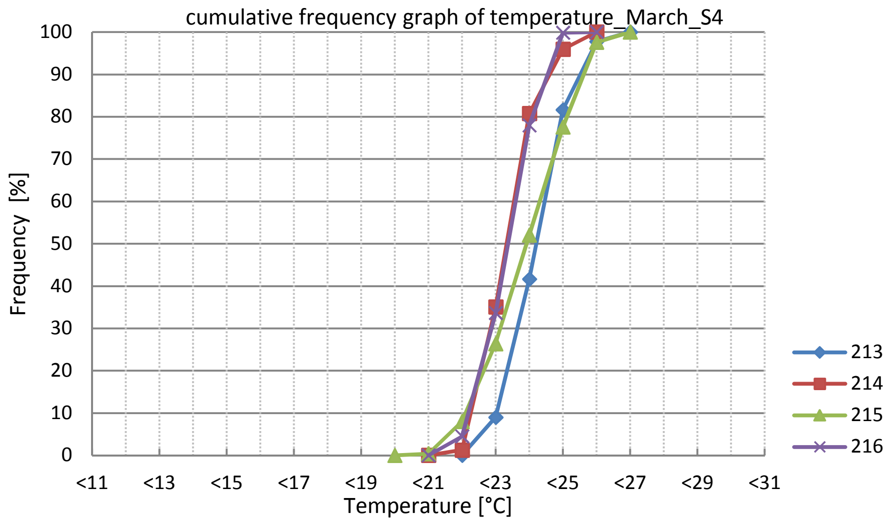


Figure 107: Cumulative frequency graph of temperature of S4 in March 2011

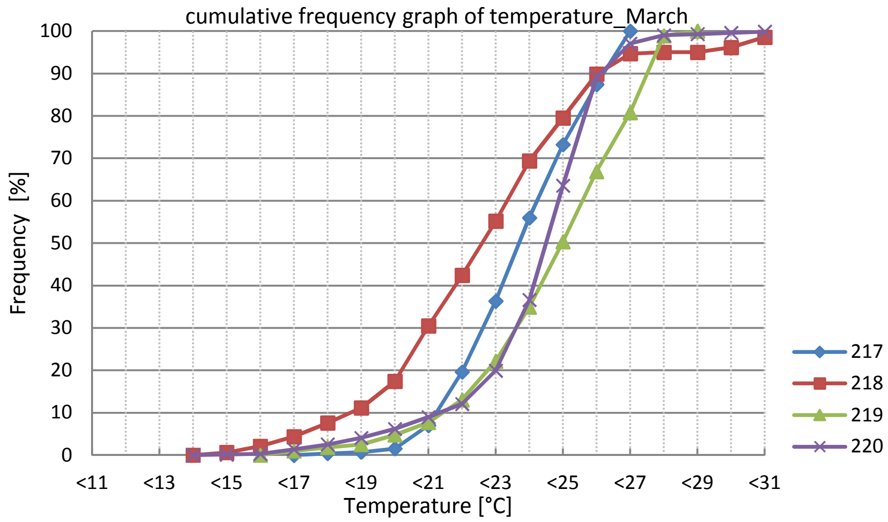


Figure 108: Cumulative frequency graph of temperature of S5 in March 2011

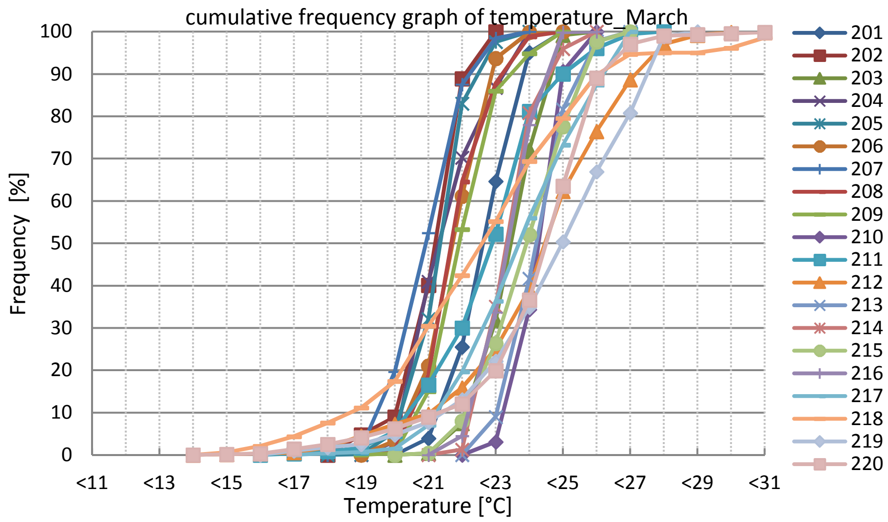


Figure 109: Cumulative freq. graph of temp. in March 2011 in all 20 classes during school time

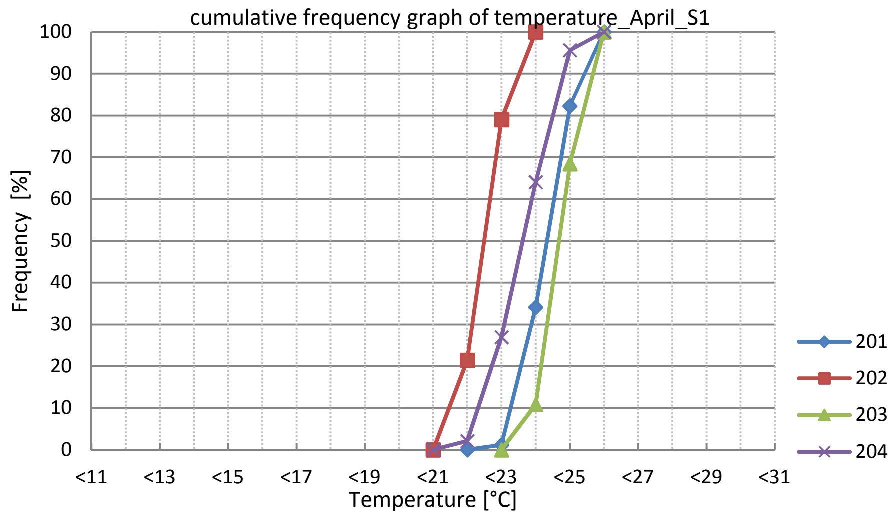


Figure 110: Cumulative frequency graph of temperature of S1 in April 2011

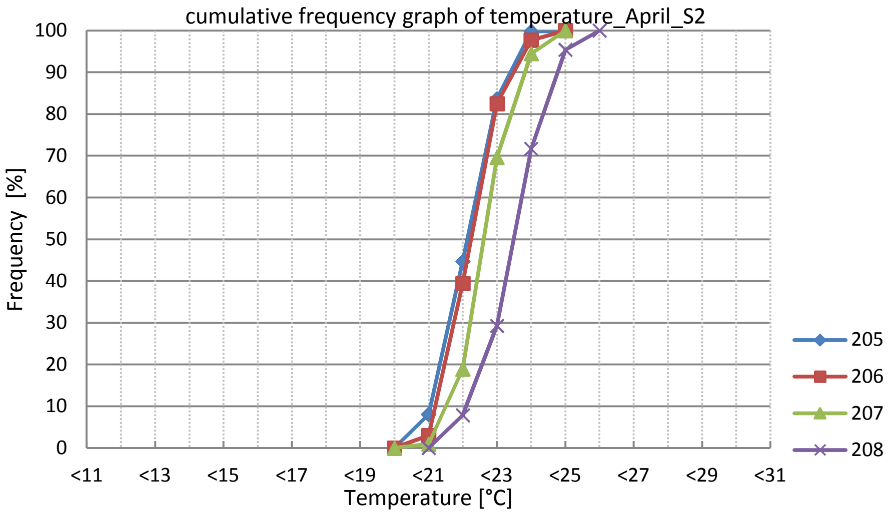


Figure 111: Cumulative frequency graph of temperature of S2 in April 2011

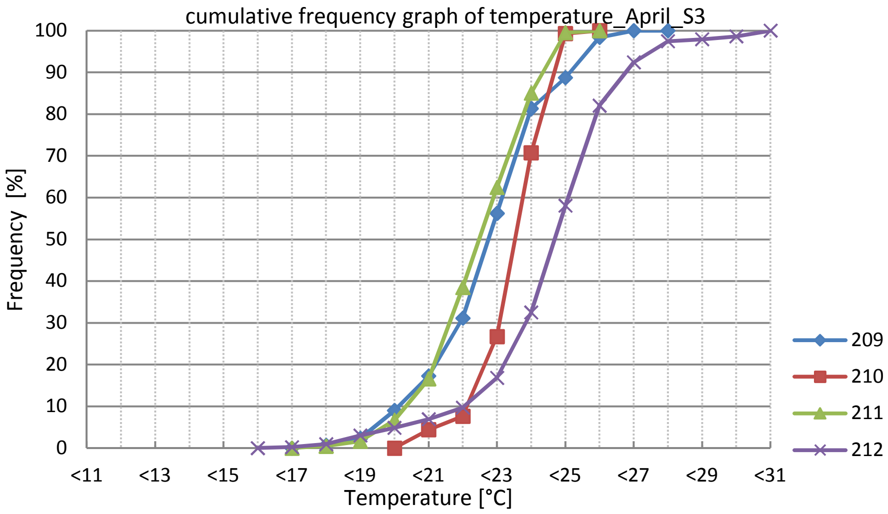


Figure 112: Cumulative frequency graph of temperature of S3 in April 2011

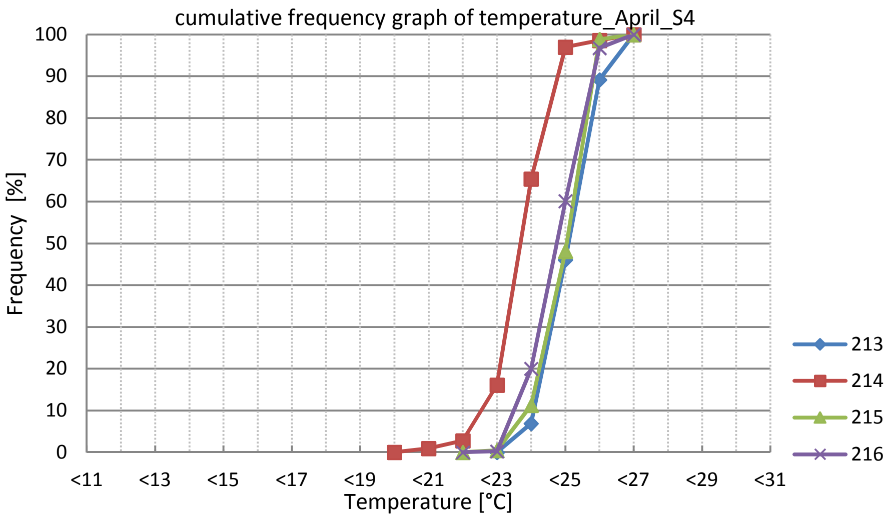


Figure 113: Cumulative frequency graph of temperature of S4 in April 2011

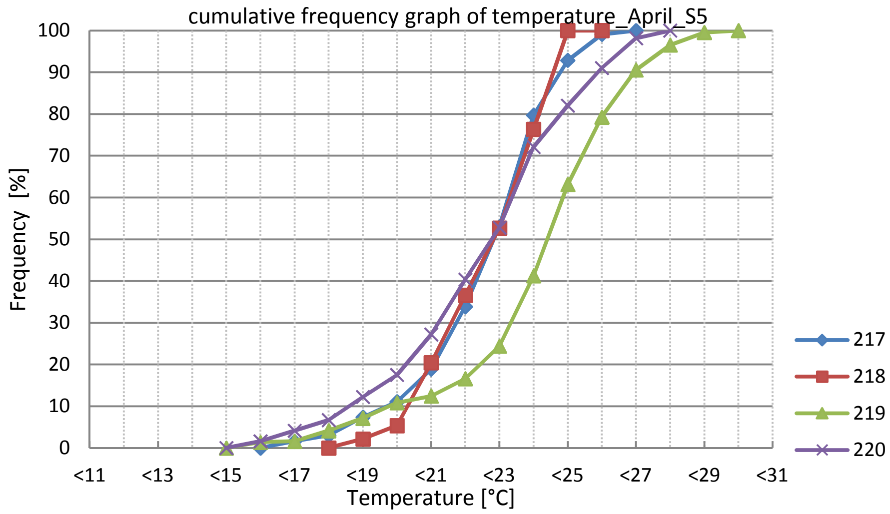


Figure 114: Cumulative frequency graph of temperature of S5 in April 2011

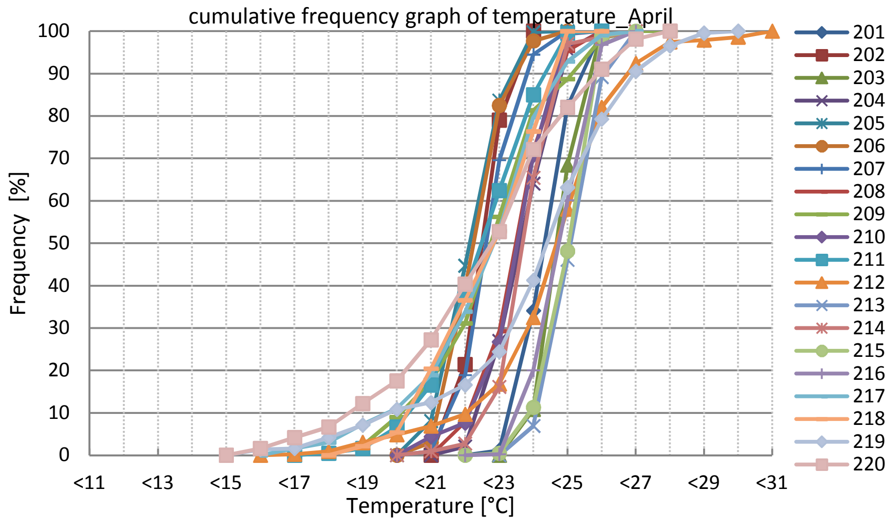


Figure 115: Cumulative freq. graph of temp. in April 2011 in all 20 classes during school time

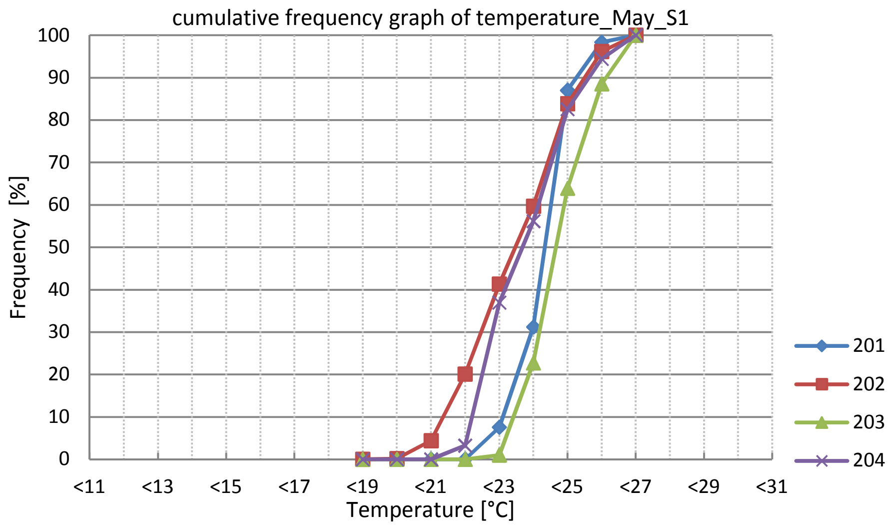


Figure 116: Cumulative frequency graph of temperature of S1 in May 2011

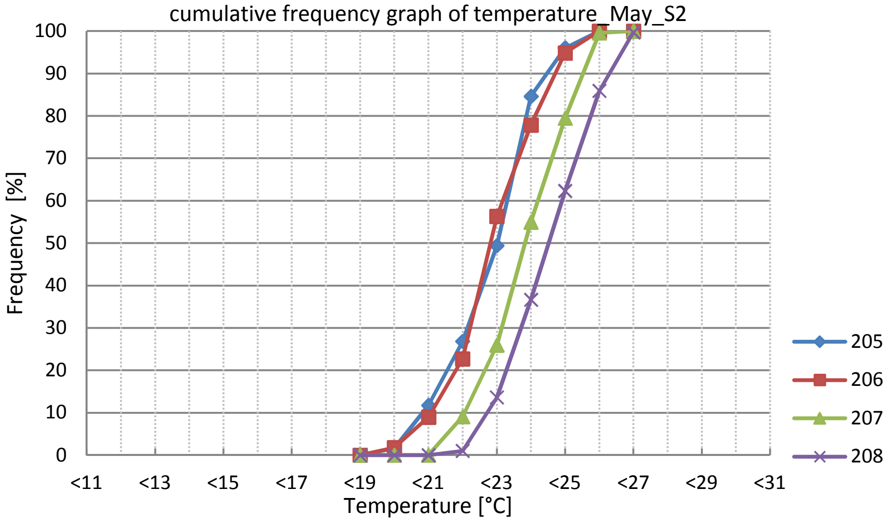


Figure 117: Cumulative frequency graph of temperature of S2 in May 2011

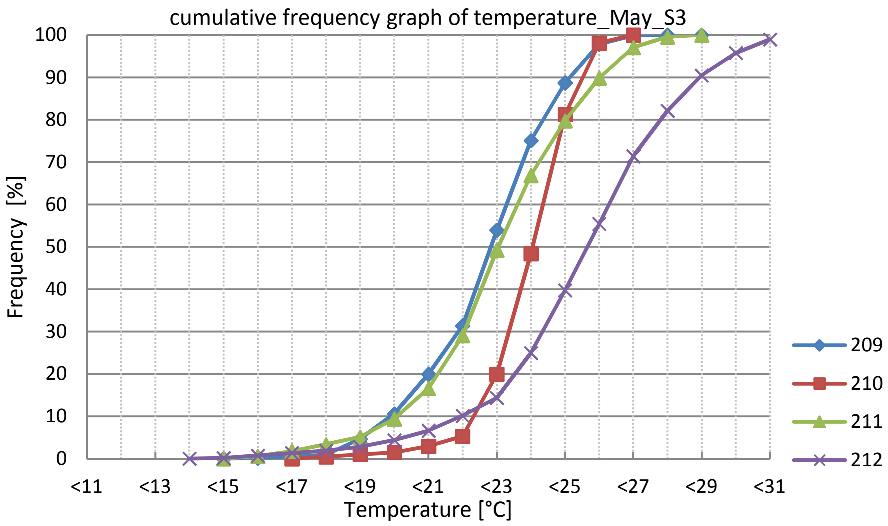


Figure 118: Cumulative frequency graph of temperature of S3 in May 2011

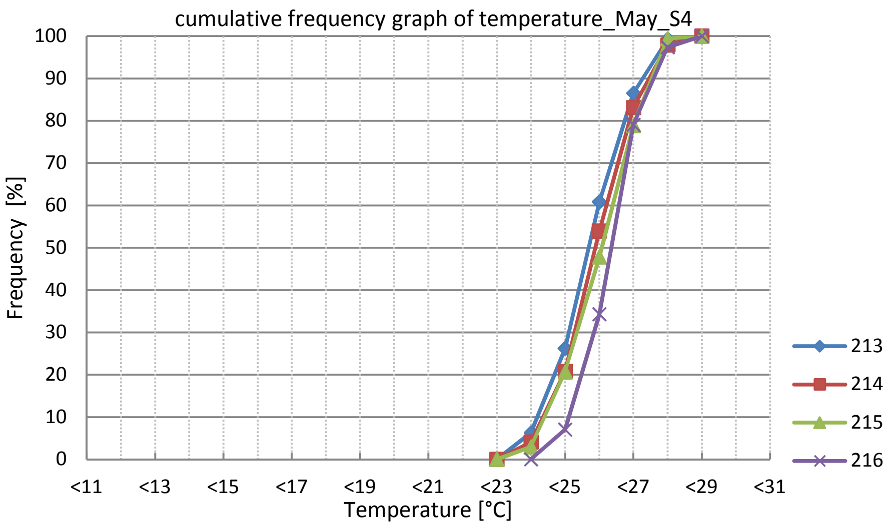


Figure 119: Cumulative frequency graph of temperature of S4 in May 2011

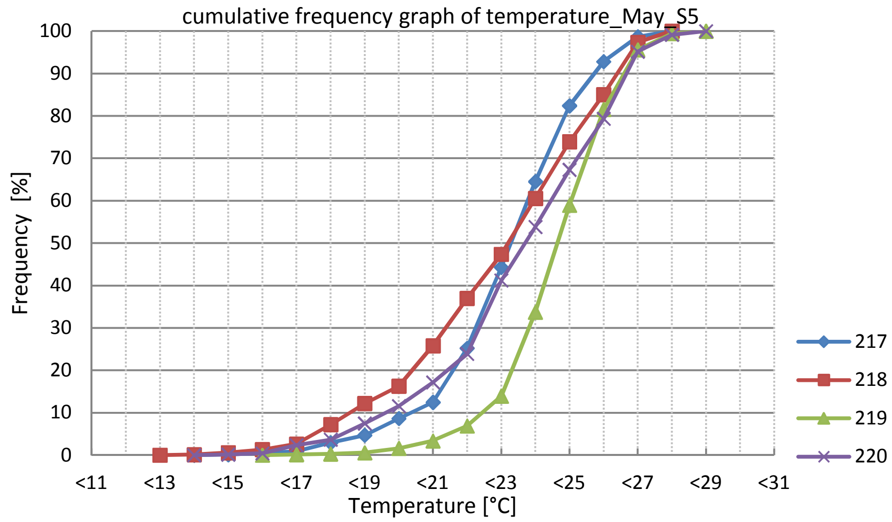


Figure 120: Cumulative frequency graph of temperature of S5 in May 2011

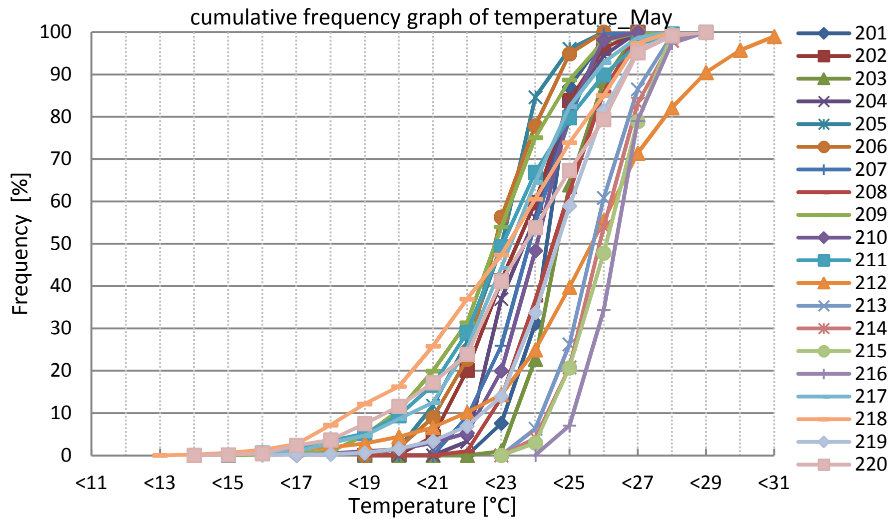


Figure 121: Cumulative freq. graph of temp. in May 2011 in all 20 classes during school time

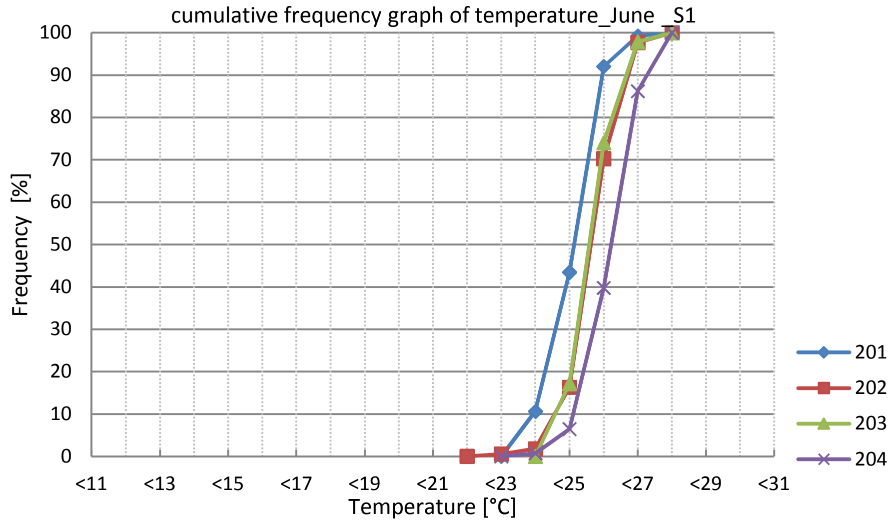


Figure 122: Cumulative frequency graph of temperature of S1 in June 2011

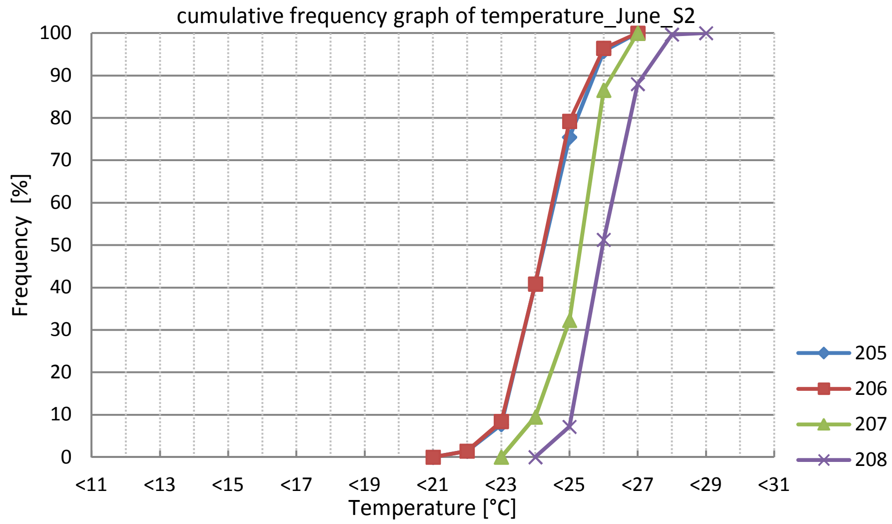


Figure 123: Cumulative frequency graph of temperature of S2 in June 2011

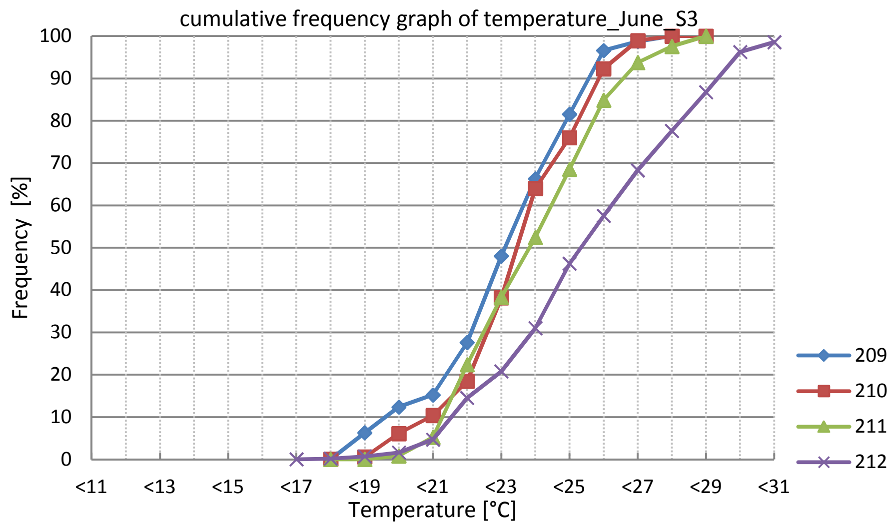


Figure 124: Cumulative frequency graph of temperature of S3 in June 2011

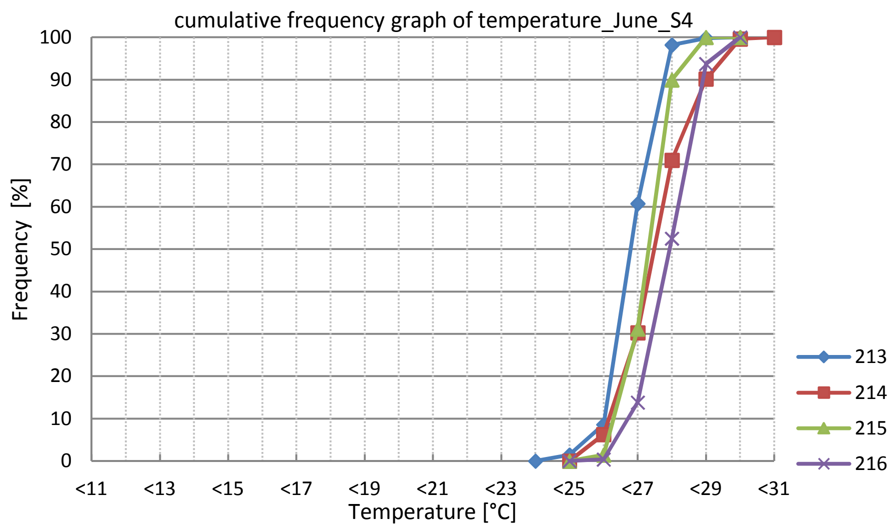


Figure 125: Cumulative frequency graph of temperature of S4 in June 2011

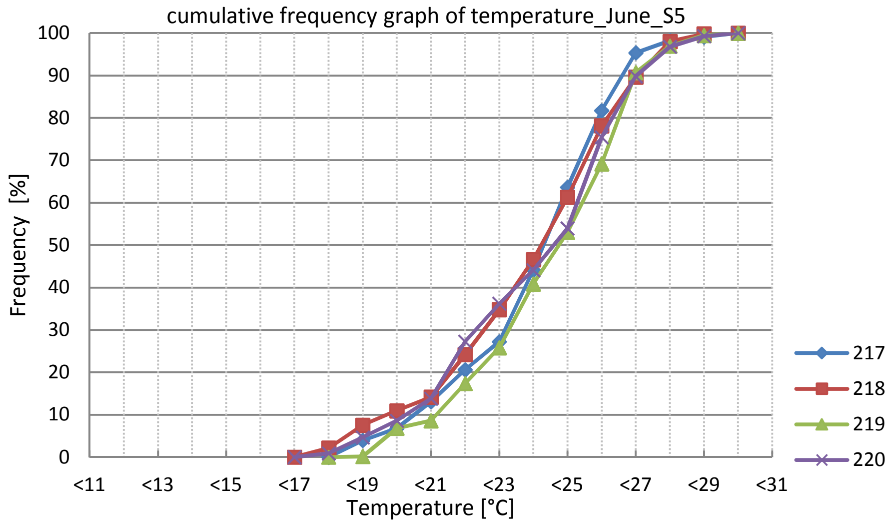


Figure 126: Cumulative frequency graph of temperature of S5 in June 2011

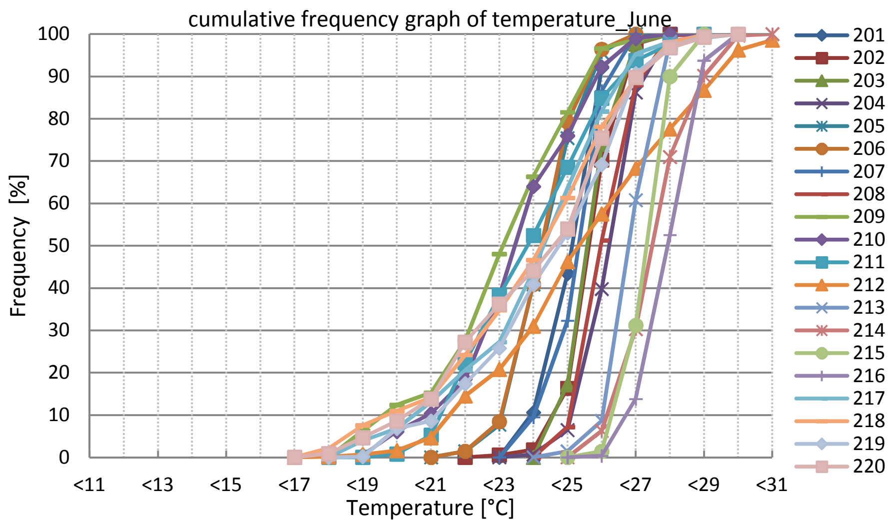


Figure 127: Cumulative freq. graph of temp. in June 2011 in all 20 classes during school time

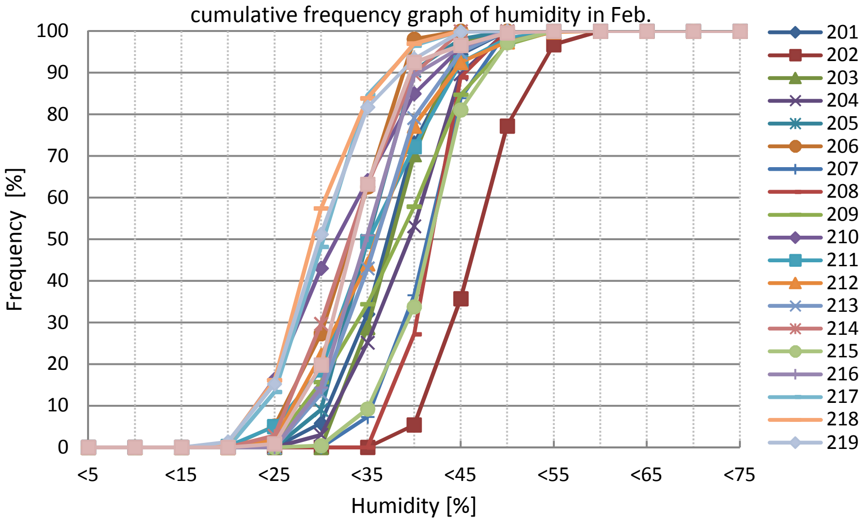


Figure 128: Cumulative freq. graph of humidity in Feb. 2011 during school time in all 20 classes

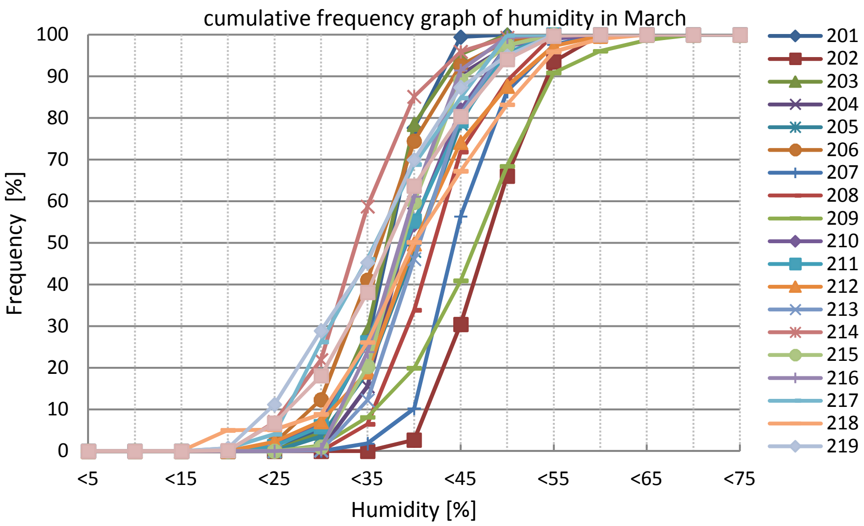


Figure 129: Cumulative freq. graph of humidity in March 2011 during school time in all 20 classes

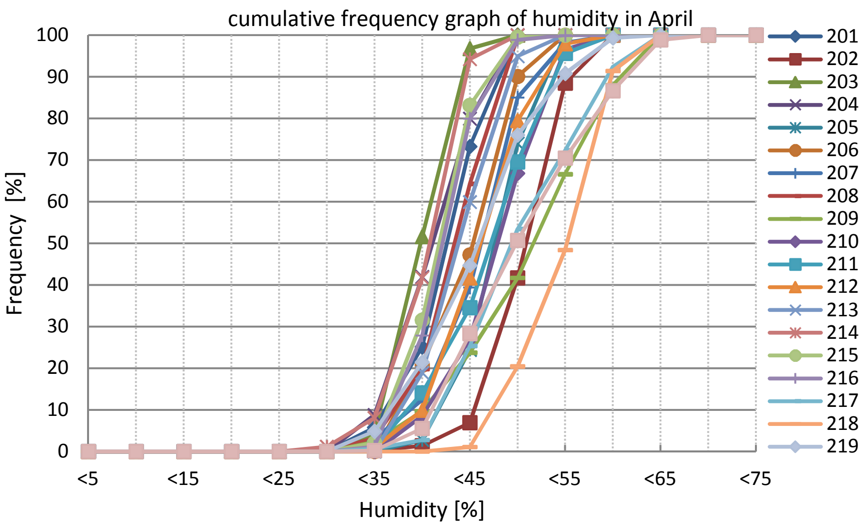


Figure 130: Cumulative freq. graph of humidity in April 2011 during school time all 20 classes

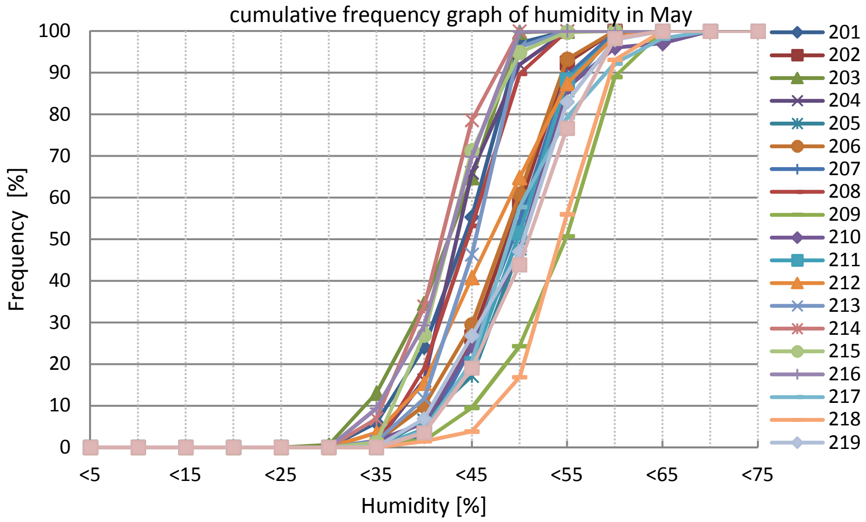


Figure 131: Cumulative frequency graph of humidity in May 2011 during school time all 20 classes

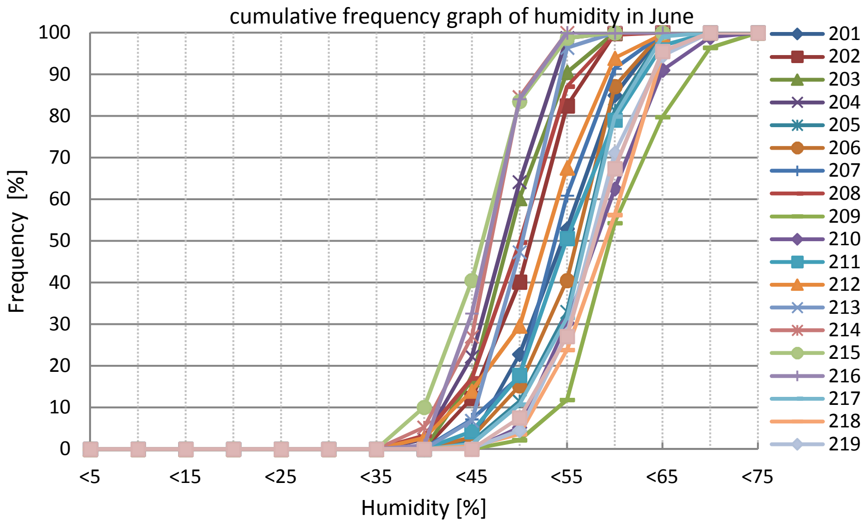


Figure 132: Cumulative frequency graph of humidity in June 2011 during school time all 20 classes

8.4. Variation of Temperature during February in S5 (Classes 501 and 502)

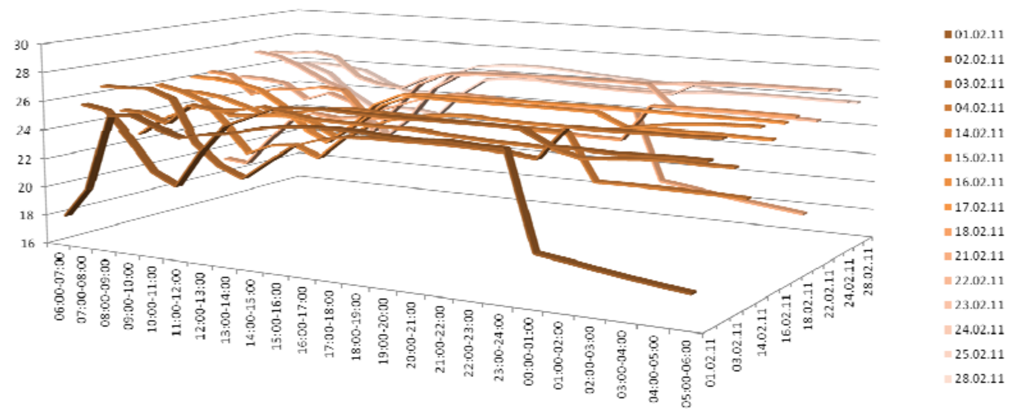


Figure 133: Temperature pattern of school opening days February in S5_ 501

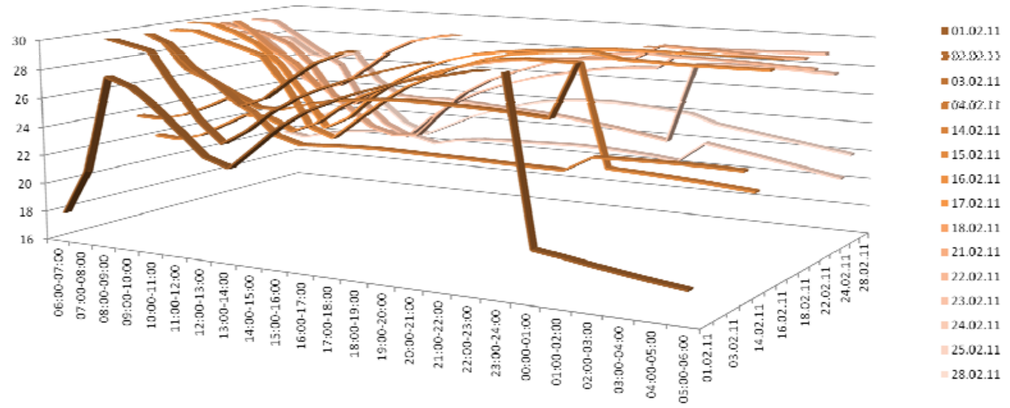


Figure 134: Temperature pattern of school opening days February in S5_ 502

8.5. Cumulative Frequency Graphs of Absolute Humidity

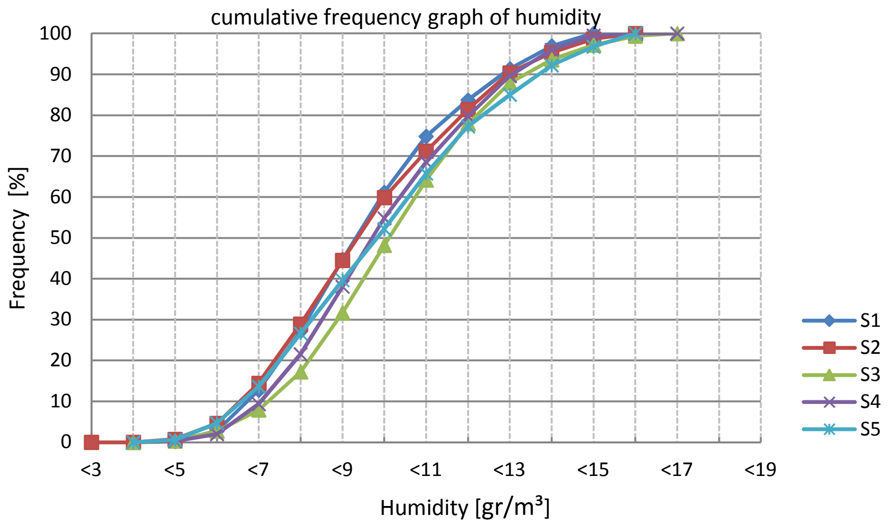


Figure 135: Cumulative frequency graph of absolute humidity of all the 5 schools

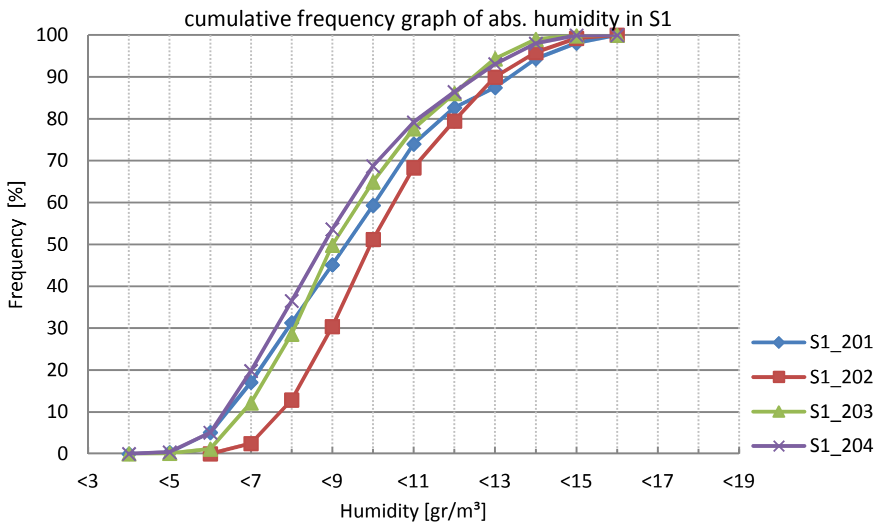


Figure 136: Cumulative frequency graph for absolute humidity of school 1 in measurement time during school hours (8:00- 13:00)

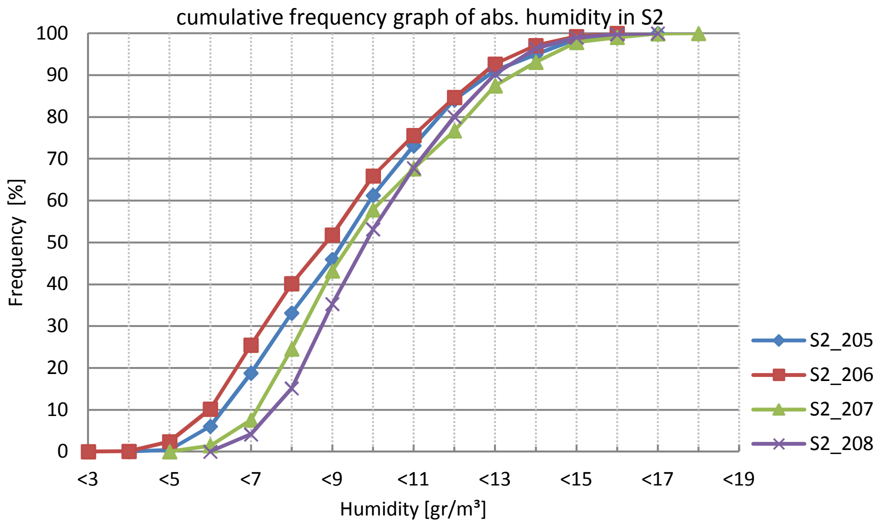


Figure 137: Cumulative frequency graph for absolute humidity of school 2 in measurement time during school hours (8:00-13:00)

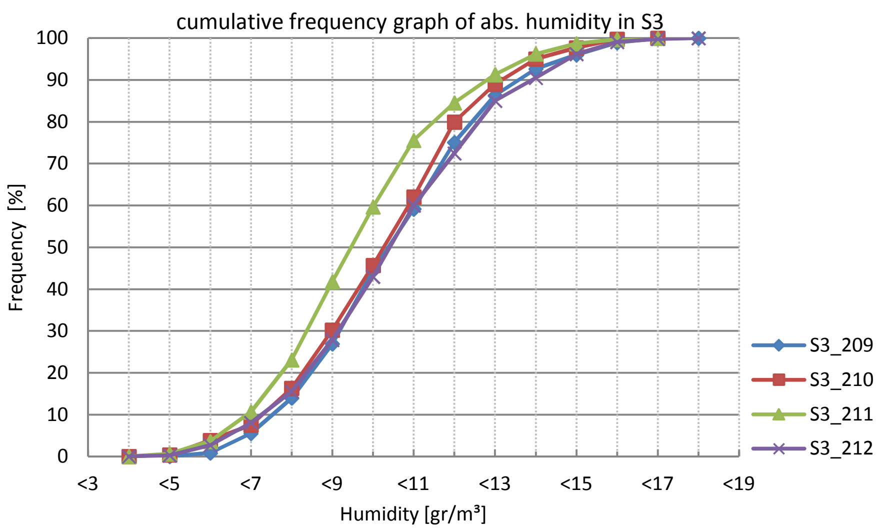


Figure 138: Cumulative frequency graph for absolute humidity of school 3 in measurement time during school hours (8:00-13:00)

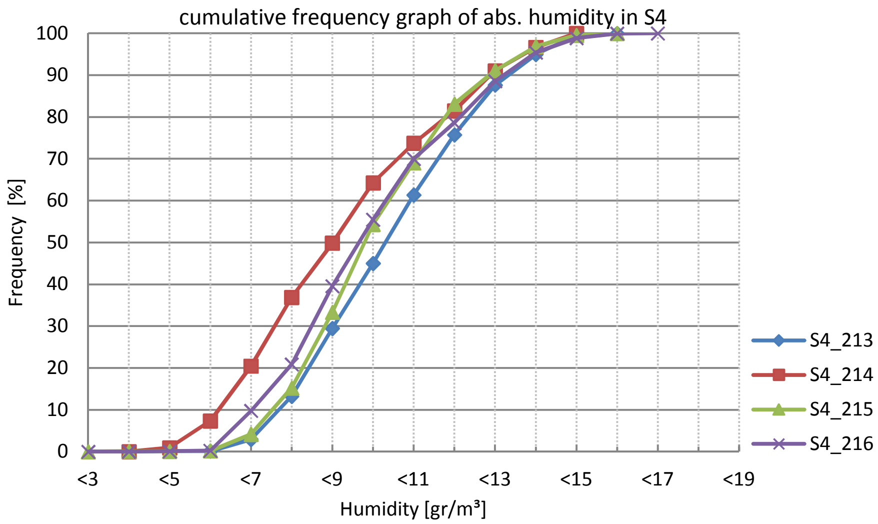


Figure 139: Cumulative frequency graph for absolute humidity of school 4 in measurement time during school hours (8:00-13:00)

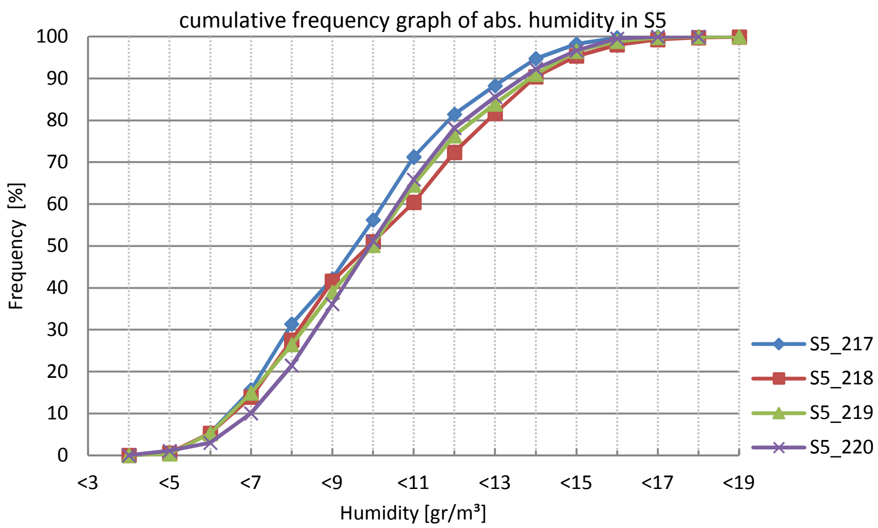


Figure 140: Cumulative frequency graph for absolute humidity of school 5 in measurement time during school hours (8:00-13:00)

8.6. Median of the Reference Day of each School during the Measurement Period

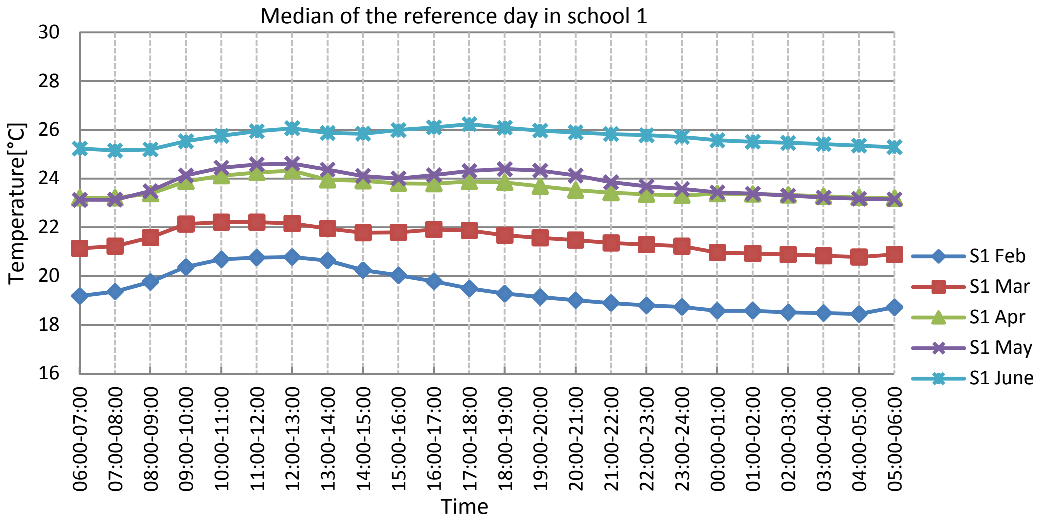


Figure 141: Temperature median of the reference day of S1

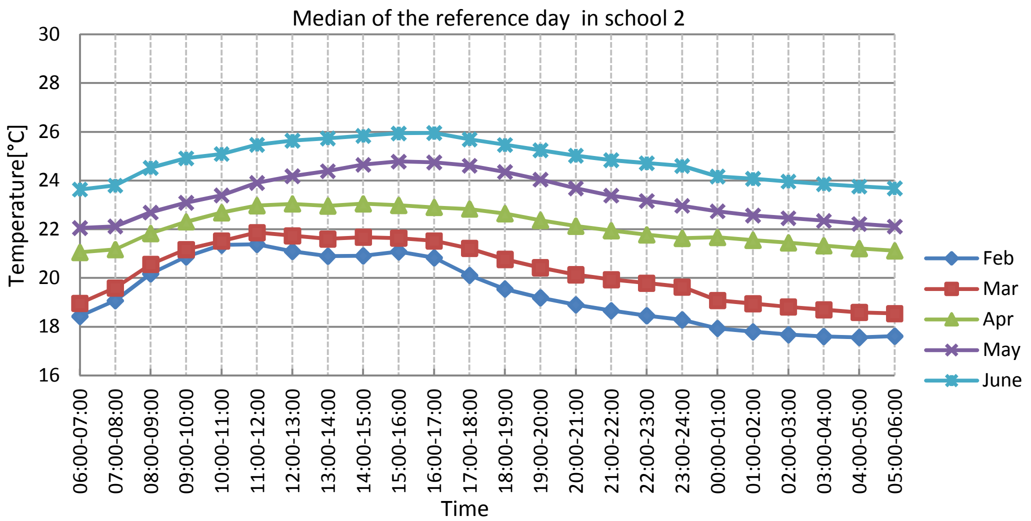


Figure 142: Temperature median of the reference day of S2

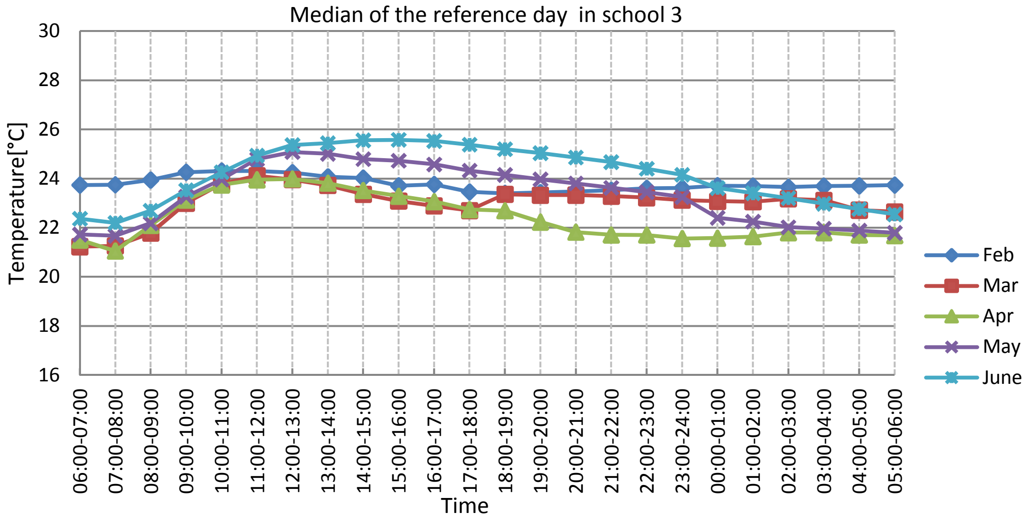


Figure 143: Temperature median of the reference day of S3

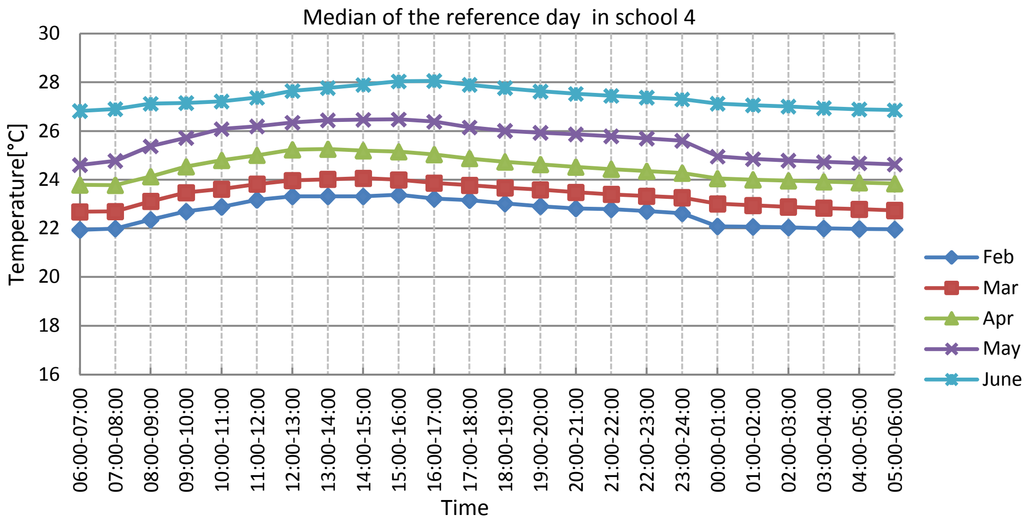


Figure 144: Temperature median of the reference day of S4

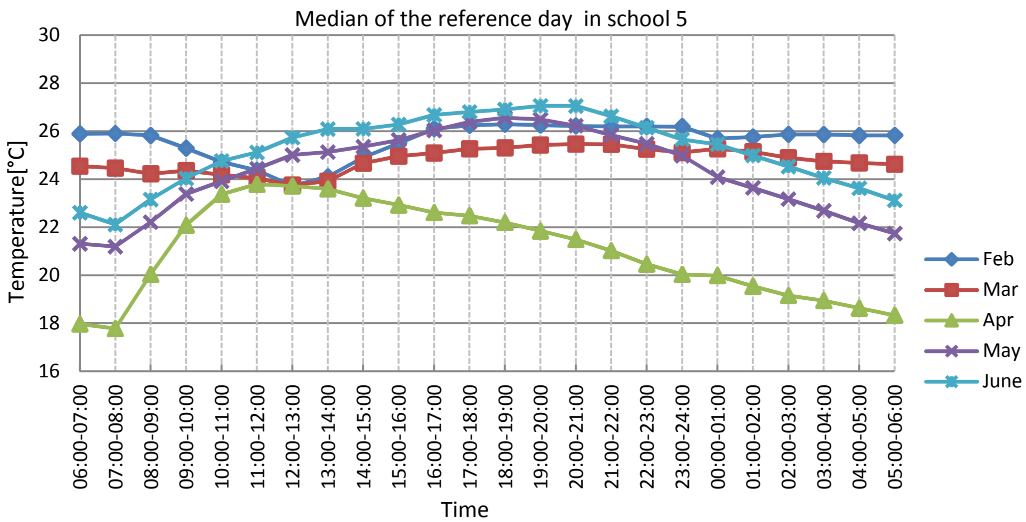
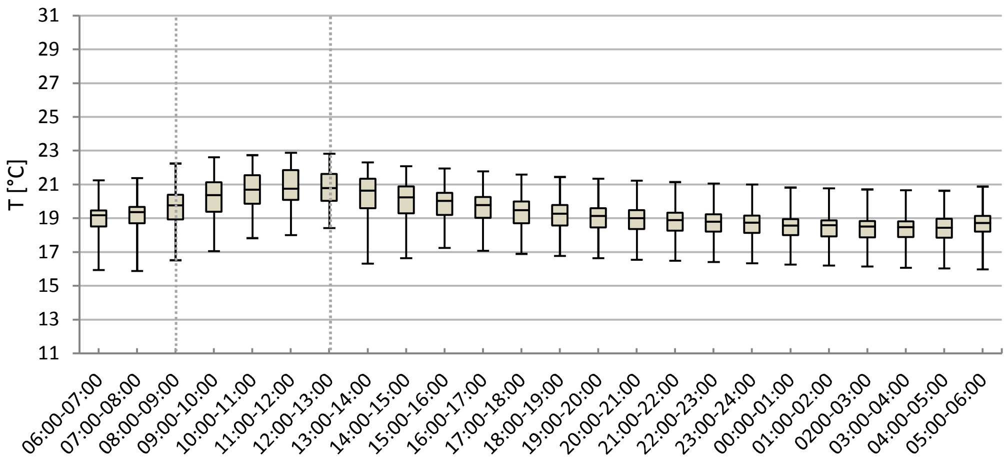
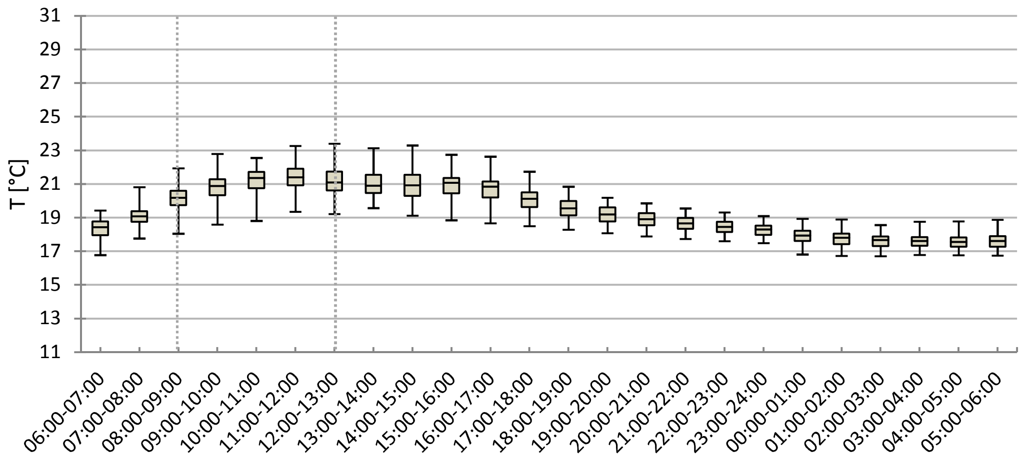


Figure 145: Temperature median of the reference day of S5

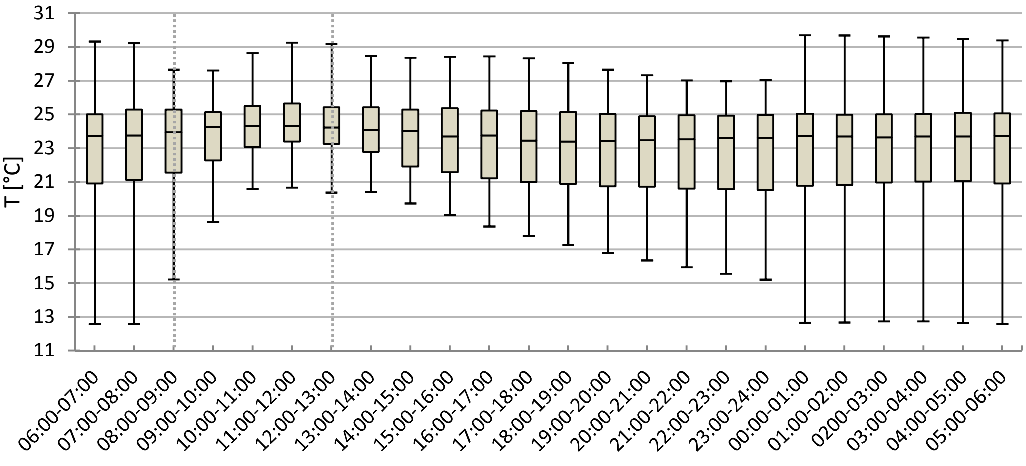
8.7. Temperature Graphs of the Reference Day of all Schools during the Opening Days of the Schools in February



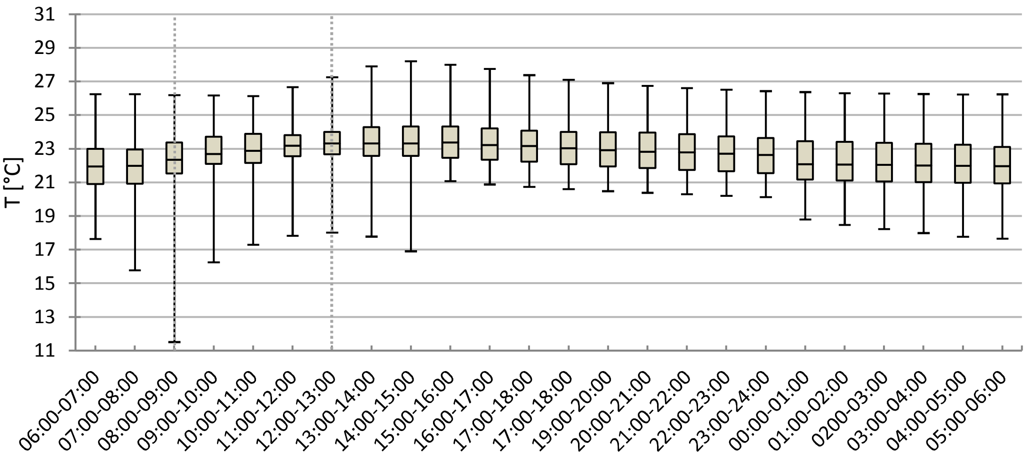
February reference day_S1



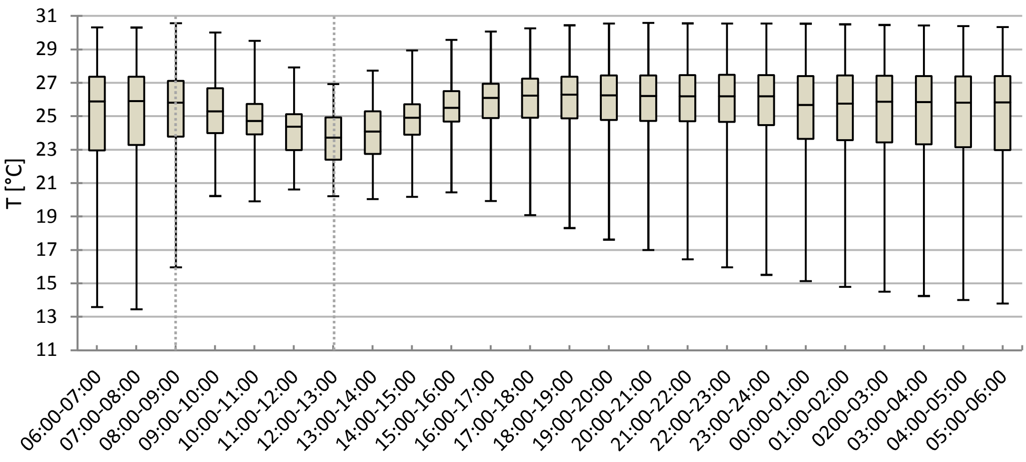
February reference day_S2



February reference day_S3

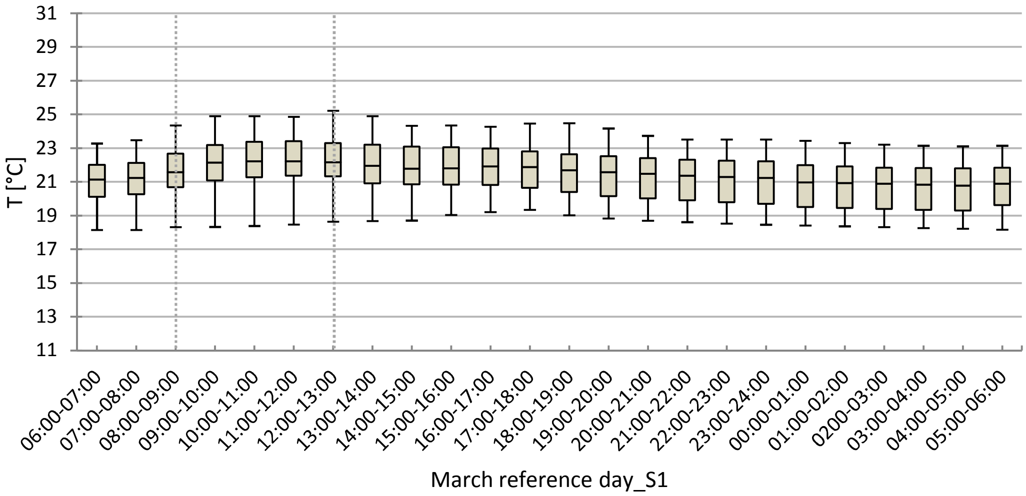


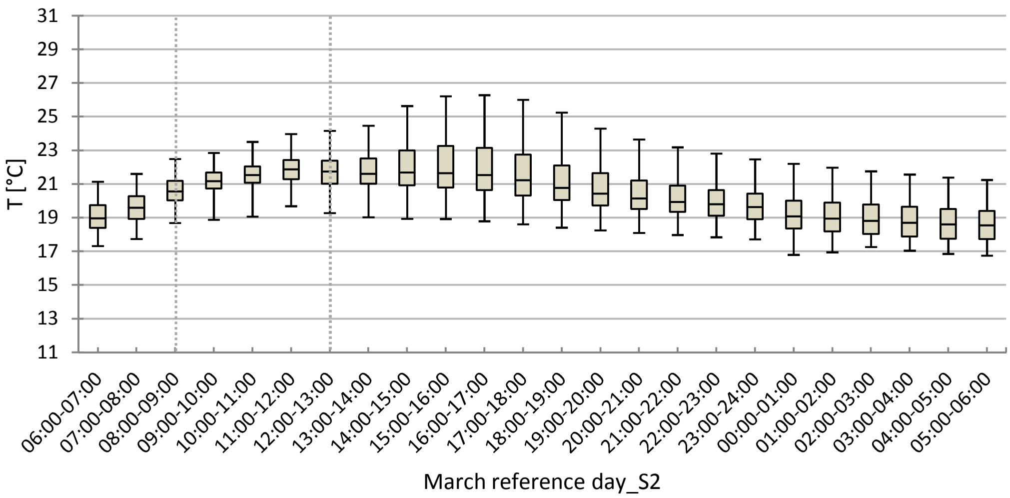
February reference day_S4

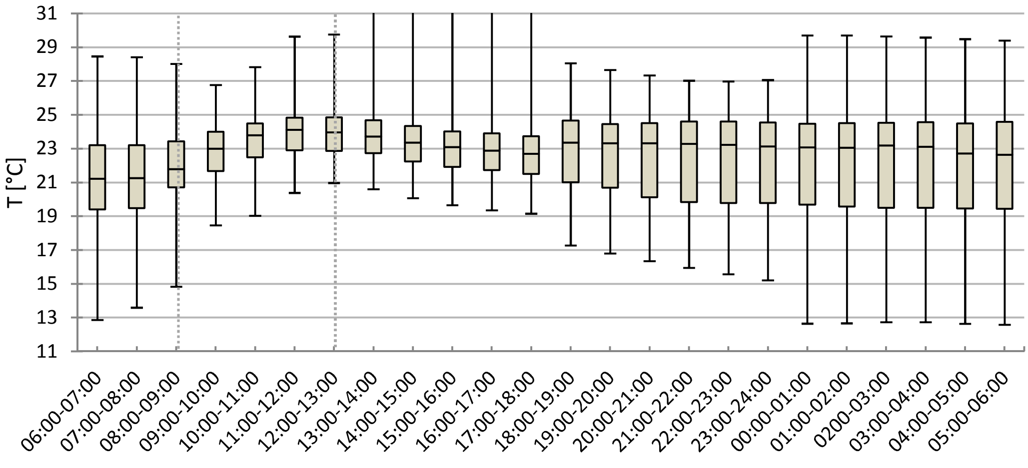


February reference day_S5

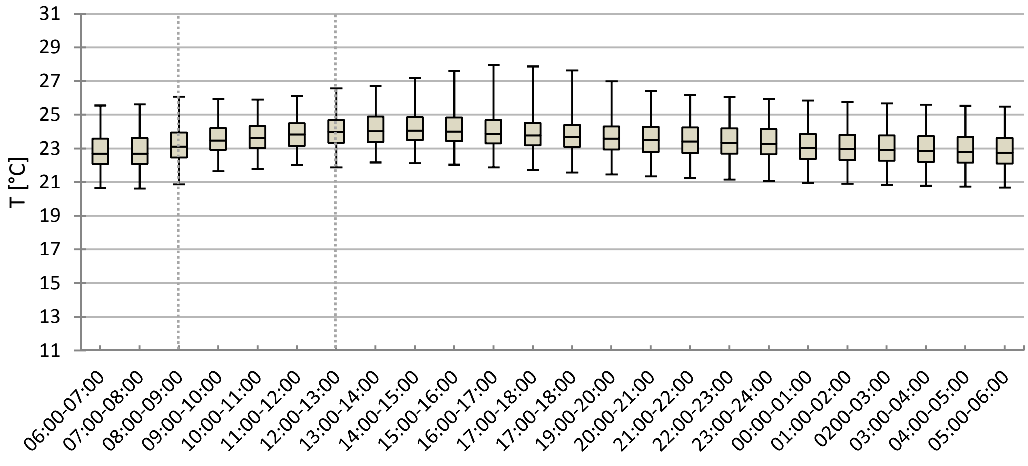
8.8. Temperature Graphs of the Reference Day of all Schools during the Opening Days of the Schools in March



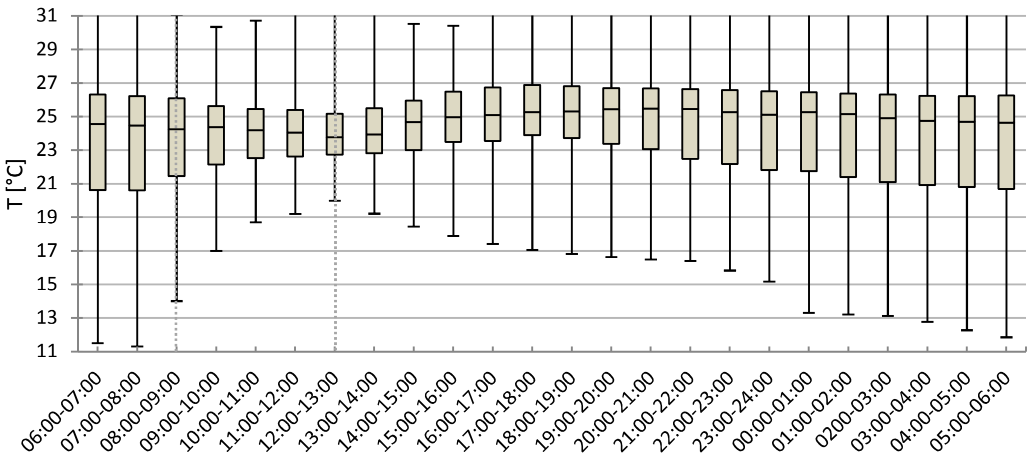




March reference day_S3

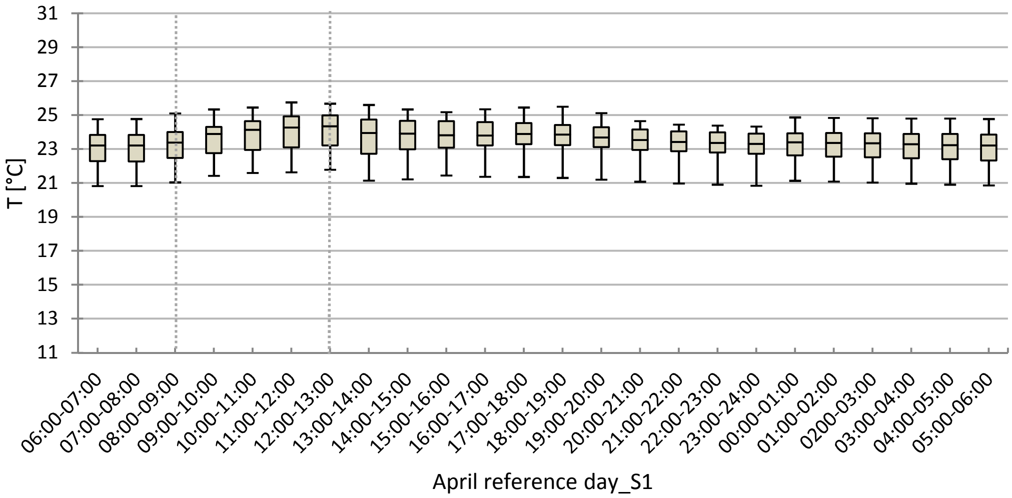


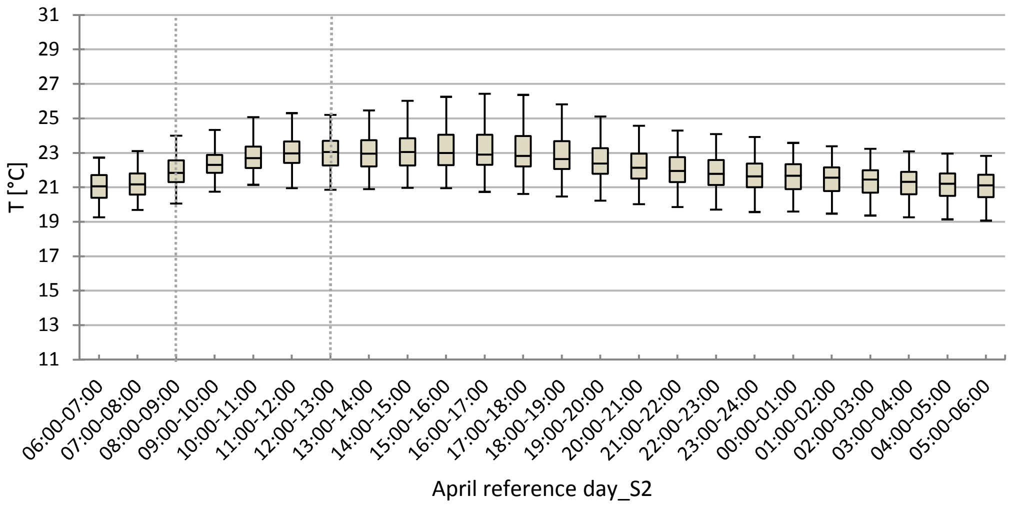
March reference day_S4

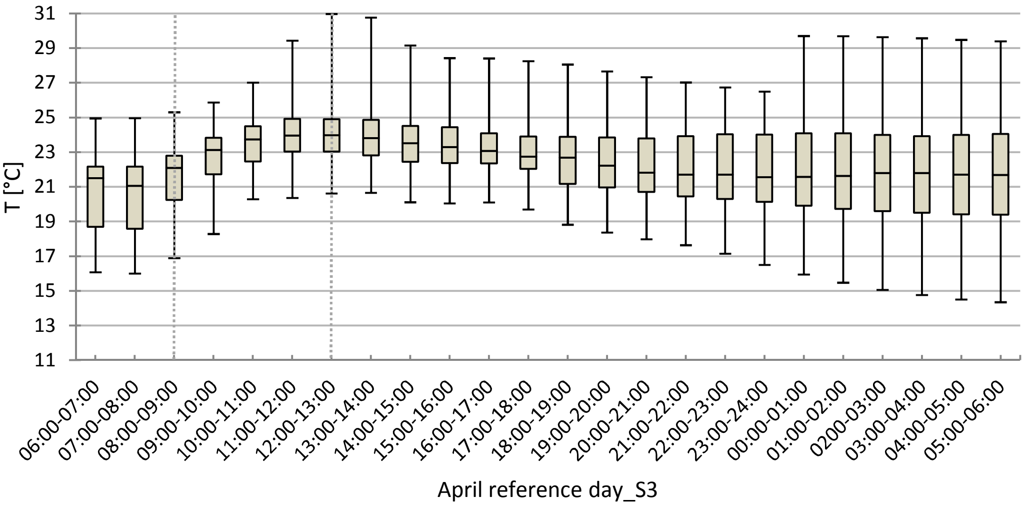


March reference day_S5

8.9. Temperature Graphs of the Reference Day of all Schools during the Opening Days of the Schools in April



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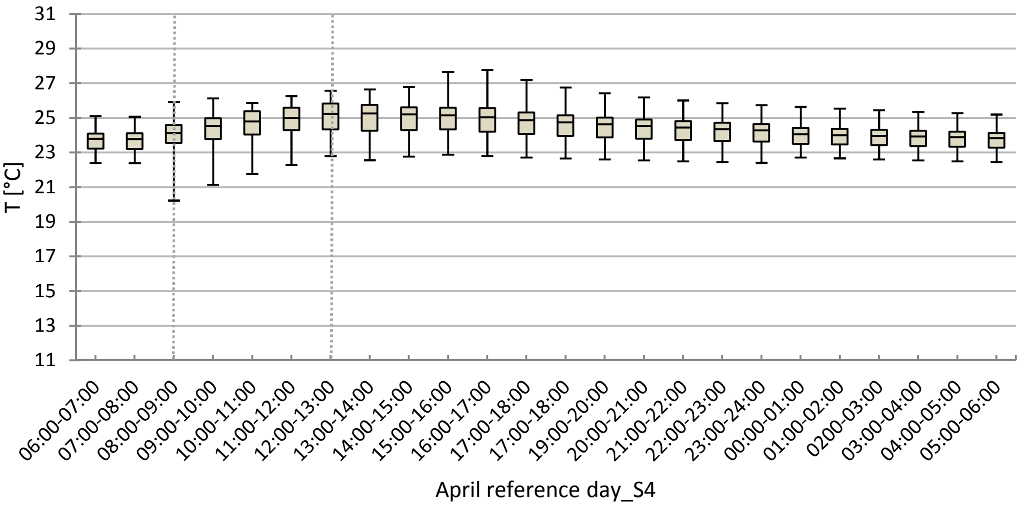
April reference day_S3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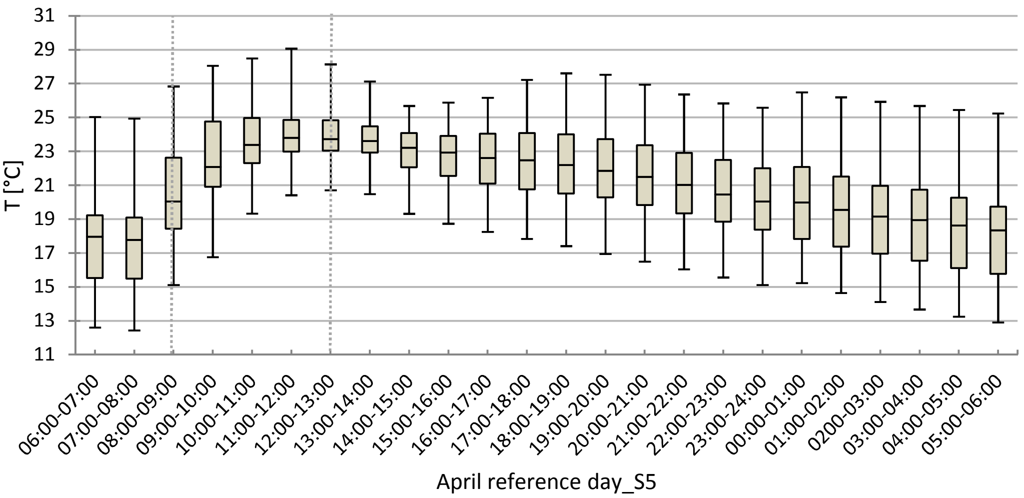
April reference day_S4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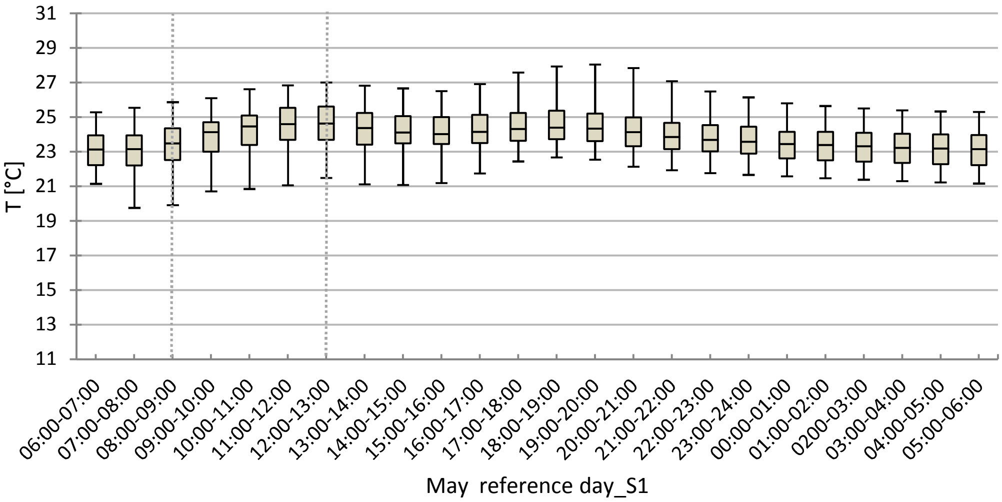
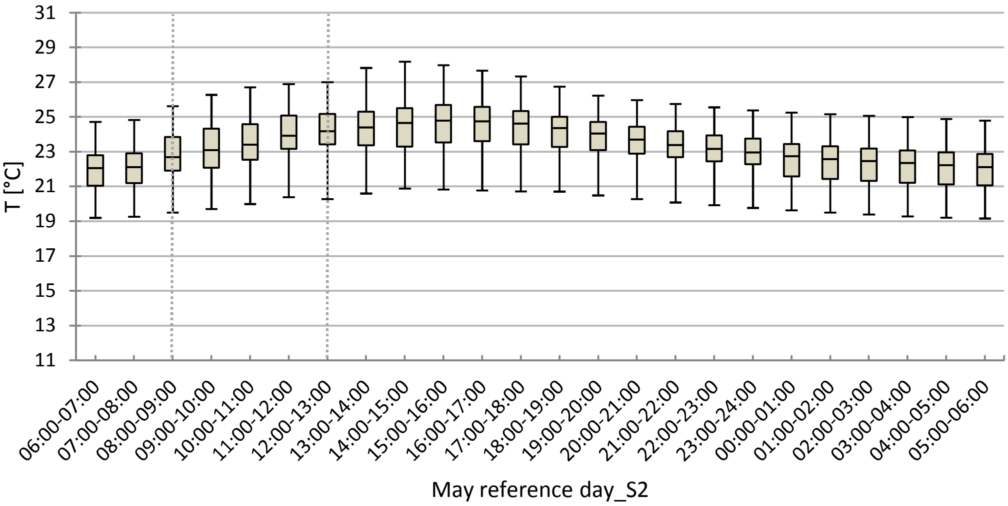
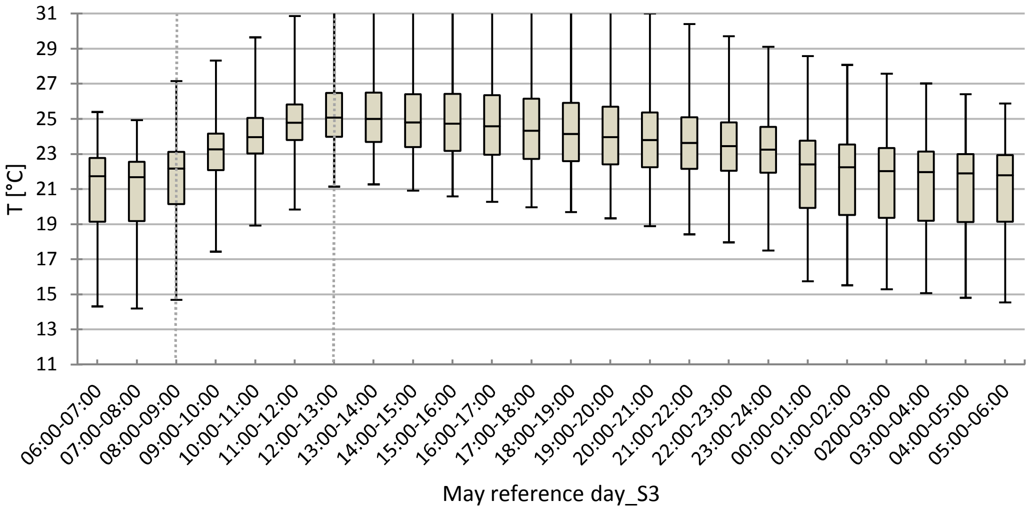
April reference day_S5

8.10. Temperature Graphs of the Reference Day of all Schools during the Opening Days of the Schools in May



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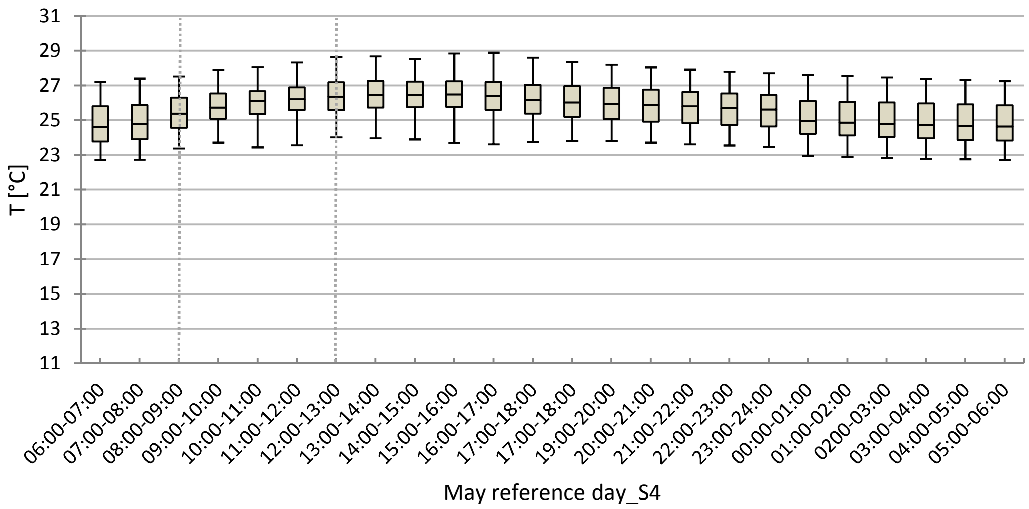
May reference day_S3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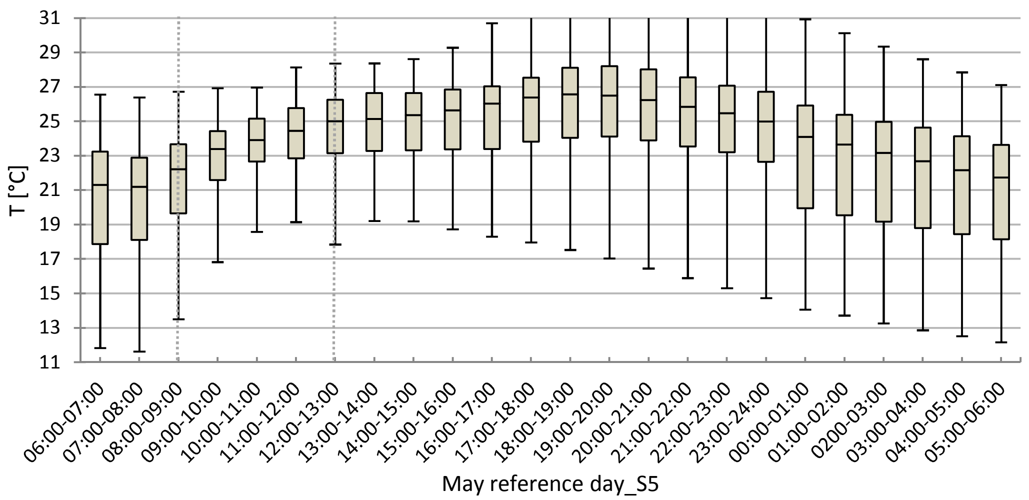
04:00-05:00
05:00-06:00
May reference day_S4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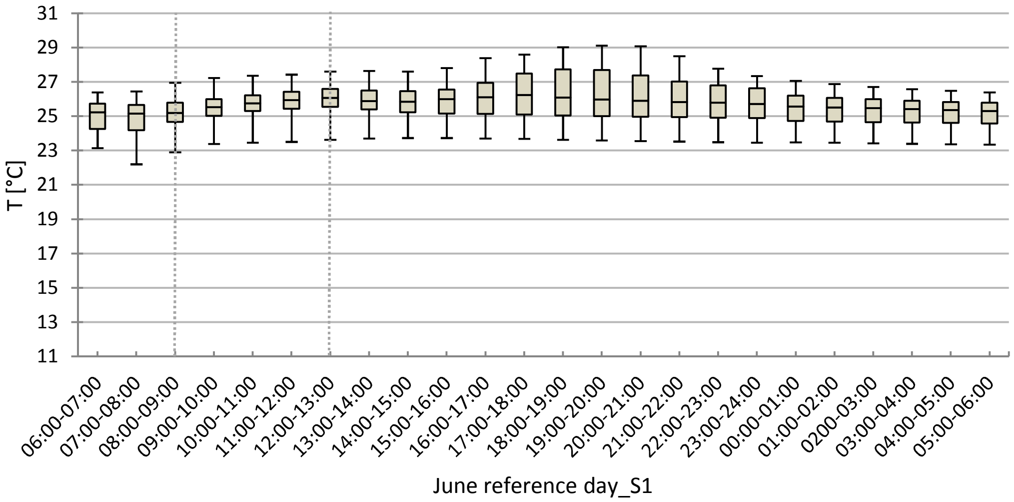
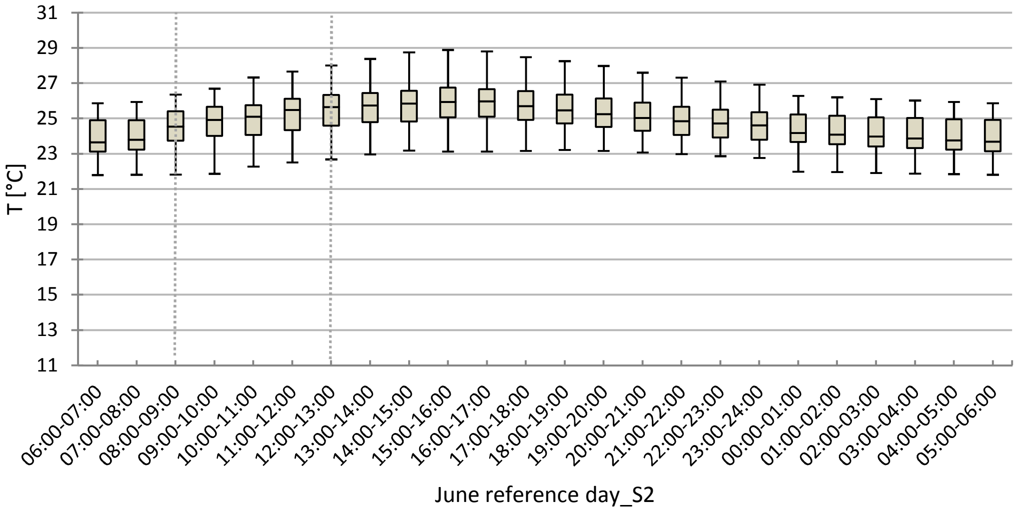
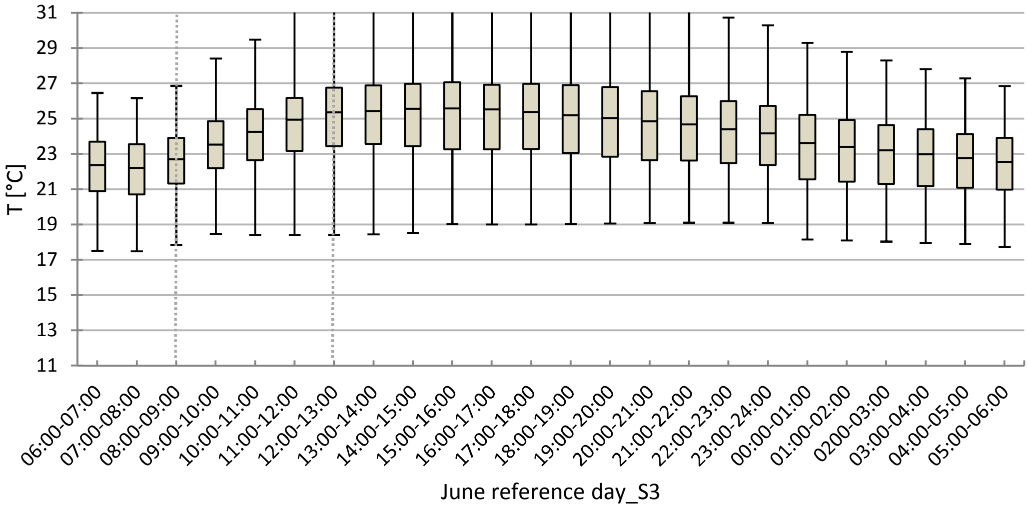
May reference day_S5

8.11. Temperature Graphs of the Reference Day of all Schools during the Opening Days of the Schools in June



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23:00-24:00
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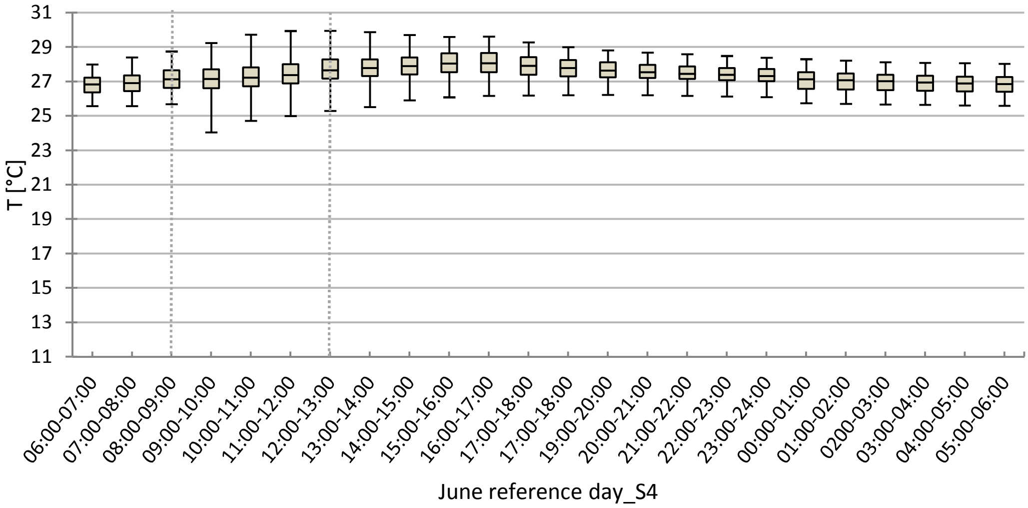
05:00-06:00
June reference day_S3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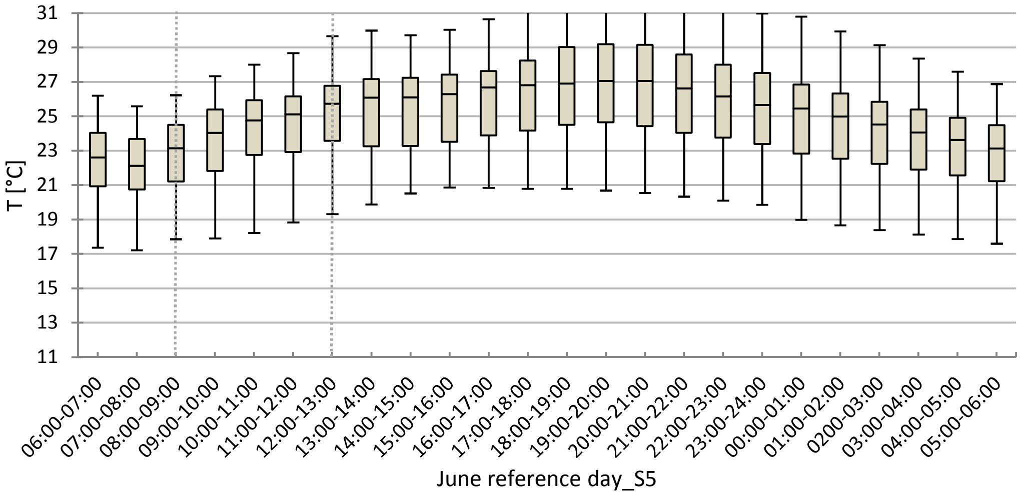
05:00-06:00
June reference day_S4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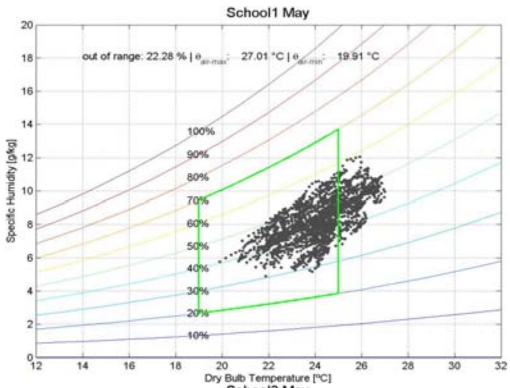
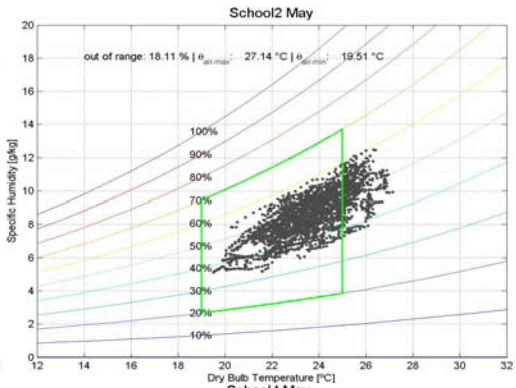
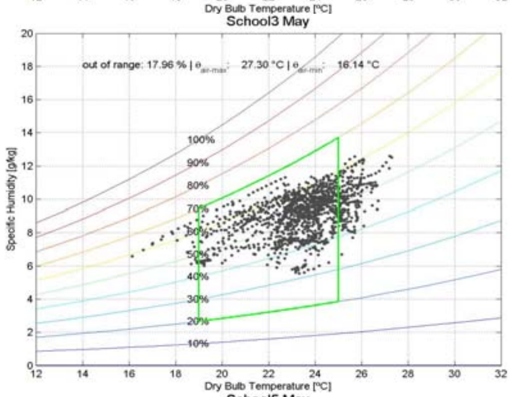
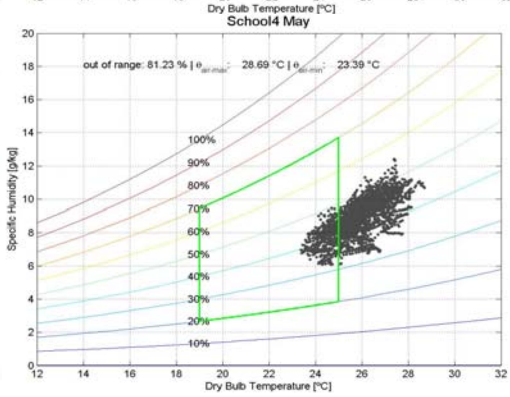
June reference day_S5

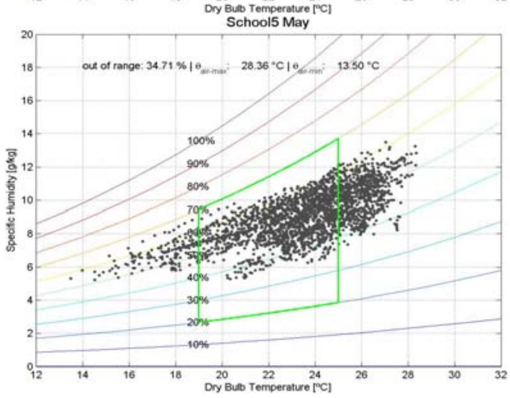
8.12. Alternative Comfort Zone for May











8.13. Temperature, CO_2 and Humidity Graphs of the Reference Day of S3 in a Particular Period

Period of measurement: 14.04.2011-20.05.2011 (20 days, 8:00-13:00)