MASTER THESIS

Evaluation of indoor air quality and thermal comfort in four university libraries in Vienna

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines

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eingereicht von

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ABSTRACT

Based on research conducted in many countries around the world, personal experience and that of fellow colleagues, in some if not many of the university libraries, the indoor environment is suboptimal due to bad lighting and ventilation systems that don´t meet the requirements.

In order to analyze the quality of the indoor environment in such locations, four libraries in Vienna were chosen as follows: Vienna University of Technology Library, University of Vienna Library, University of Veterinary Medicine Library and Academy of Fine Arts Library. The aim of this research was to investigate if changes in the lighting and air conditioning systems could provide a safer and more comfortable indoor environment for its users. The four buildings that were analyzed are in different locations around Vienna, two were built in the 1800s and the other two nearly 20 years ago.

The research was carried throughout a period of ten months during which time, a collection of data for temperature, humidity indices, and carbon dioxide concentrations was acquired. The data was assessed through sensors mounted in each selected location targeting a better understanding of the indoor air quality and thermal comfort.

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1. Introduction

1.1. Motivation

Reading is the main task in libraries. Proper lighting and good air quality are crucial to the overall comfort of a library´s users.

Technology nowadays offers people the comfort of working from home and accessing information via internet is so inevitable. We may ask: why do we need libraries in the digital age? Besides the fact that we need to preserve human knowledge for future generations, the issue is that of distinguishing between reliable and unreliable information.

When designing a library as much attention should be paid to the indoor environment and lighting system as to the building structure itself because these are important influencing factors to be considered. Recent studies show that quality of light, temperature and humidity affect a student´s productivity, behavior and concentration while learning. Moreover good lighting and ventilation systems have the potential to add value, reduce costs and enhance performance. Therefor the author chose to analyze the reading rooms inside four of Vienna's most representative libraries with focus on light, temperature, relative humidity and carbon dioxide concentrations to observe the internal conditions and determine if improvements are needed.

The libraries chosen are different from many points of view: year of construction, architectural style, location and the installations with which they are equipped. The University of Vienna Library and the Academy of Fine Arts Library were built in the 19^{th} century and the two more recently built ones are the University of Technology Library and the Veterinary University Library.
To assess the thermal comfort, indoor temperature, relative humidity levels and carbon dioxide concentrations were measured from May 2012 until February 2013.

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1.2. Background

There are very few studies conducted regarding the indoor air quality and the conditions that should be met in libraries. Due to the fact that research on indoor air quality involves many scientific disciplines, there is considerably less information in literature, for libraries in particular compared to other related environments like office buildings, schools and so on.

An inadequate indoor environment affects well-being, productivity and can lead to a series of health risks from dust accumulation (in most libraries book stacks are kept in the reading rooms), insufficient ventilation, high concentrations of carbon dioxide and poor lighting.

Many building codes and design criteria are not based on consequences to be had on human performance and health (e.g., lighting requirements). Ventilation requirements along with those for temperature and humidity have been analyzed, more on the basis of meeting comfort criteria (Samet 2003). Not maintaining clean indoor environments results in productivity losses and more error in the work that is being done.

New York University, School of Medicine and Brigham Young University have undergone a 16 year study which showed that long term exposure to fine particulate matter (dust) is an important risk factor for lung cancer and heart diseases (Hreha 2007).

There are hundreds of studies and researches that have been carried out in office buildings, schools and other type of buildings but not in libraries. Some studies carried out in Europe and The United States having libraries as their main focus concentrated on symptoms related to SBS (Sick Building Syndrome) in habitual library users, as they spend many hours inside such environments. They have shown that sometimes in these environments, levels of formaldehyde and VOCs above the limits fixed by international bodies are detected. They also demonstrate an association between these high concentrations and a number of symptoms encountered in library users (Righi et al. 2001).

Effects on human health were analyzed thoroughly in regard to different sources of air pollution with conclusive findings. This thesis was conducted from a technical discipline´s point of view and will analyze four distinct parameters: temperature, relative humidity, carbon dioxide concentrations and light. The objective was to observe how these parameters influence the learning environment inside the reading rooms of libraries.

Unfortunately, only a few researches on combined effects of the indoor environmental parameters in Europe and the rest of the world are available thus the need for more studies in this field is high.

1.3. Objectives

Along with energy inefficiency, poor air quality has been another side-effect of the post air conditioning building design. Because most modern buildings are temperature controlled, they are designed to be airtight.

This research compares two libraries built near the turn of the 19th to 20th century, the University of Vienna Library and the Academy of Fine Arts Library; to two more recently built libraries, the University of Technology Library and the Veterinary University Library. The two older libraries have interior spaces that cannot be easily reached by natural light and air. Whereas the two more modern libraries have large floor plans with wide windows, thus with a higher exposure to daylight and natural ventilation.

The lack of natural ventilation can not only make buildings expensive to cool, it also traps harmful toxins that can do serious damage to people's respiratory systems. Toxins come from a variety of sources: books, paints and carpeting, to name a few.

Carbon dioxide monitors were installed inside the reading rooms of the four libraries to see if carbon dioxide concentrations are at a safe level. Also temperature, relative humidity and lighting levels were monitored throughout a period of ten months, in order to see if theses specific parameters that a library environment must maintain in order to sustain the physical condition of the books and more importantly, the wellbeing of the occupants, are met.

2. Methodology

The question at issue in this thesis is whether the indoor environment of the four mentioned libraries is a safe one from a health point of view and optimal for the tasks that are performed in these buildings. There is a need to evaluate the long-term performance of the buildings in respect to the indoor environment.
This is done by evaluating the environment of typical rooms representing different zones in the building.

Because of time and financial aspects, for this research only the reading rooms of the libraries where chosen to be monitored. The evaluation was based on measurements and consisted of:

- thermal criteria for winter;
- thermal criteria for summer;
- air quality - CO_2 concentrations;
- lighting criteria;

Values outside the recommended range should be acceptable for short periods during a day. Therefore, it is recommended that 3-5% of the time (working hours) the calculated or measured values can be outside the range. The 3-5% is to be used for daily (15-25 minutes during a working day), weakly (24-120 working minutes) and yearly (50-100 working hours) measurements (Olesen 2006).

2.1. Standards and indoor requirements in libraries

In order to achieve thermal comfort one needs to consider primary factors such as air temperature, air speed, humidity and human perception. Moreover by analyzing carbon dioxide levels (air pollution) and light intensity, an overall comfort can be assessed. Standards define an acceptable indoor air quality as air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

2.1.1. Light

Lighting is one of the building systems that can be controlled. The system should provide a high level of lighting control by occupants or groups in a multi-occupant space to enhance the productivity, comfort and wellbeing of building occupants.

Standards give values for daylight factor (at center of room), luminance uniformity, control and dimming, uniform glare rating, ease of modification of lighting, light color (color temperature) and color rendering index Ra. Typical lighting requirements for a variety of tasks as recommended by the standard ÖNORM EN 12464-1:2011, are given in Table 1 below.

Table 1. Educational premises - Educational Buildings ÖNORM EN 12464-1:2011

Ref. No.	Type of area, task or activity	E_m lx	UGR_L -	U_o -	R_a -	Specific requirements
5.36.18	Stairs	150	25	0.40	80	
5.36.19	Student common rooms and assembly halls	200	22	0.40	80	
5.36.20	Teachers rooms	300	19	0.60	80	
5.36.21	**Library: bookshelves**	**200**	**19**	**0.40**	**80**	
5.36.22	**Library: reading areas**	**500**	**19**	**0.60**	**80**	
5.36.23	**Library: counters**	**500**	**19**	**0.60**	**80**	
5.36.24	Stock Rooms for teaching materials	100	25	0.40	80	
5.36.25	Sports halls, gymnasium, swimming pools	300	22	0.60	80	See EN 12193 for training conditions
5.36.26	School canteens	200	22	0.40	80	
5.36.27	Kitchen	500	22	0.60	80	

2.1.2. Temperature

Standard ÖNORM EN 15251:2007 provides the operative temperatures (room temperatures) valid for office buildings and other buildings of similar type as shown in Table 2. The temperature limits in figure are based on comfort studies in offices; nevertheless, based on general knowledge on thermal comfort and human response, the assumption can be made that the limits may apply to other (comparable) buildings used mainly for human occupancy with mainly sedentary activities.

Measurements should be made where occupants are known to spend most of their time and under representative weather condition of cold and warm season. The measurement period for all measured parameters should be long enough to be representative.

Table 2. Examples of recommended values of indoor temperatures ÖNORM EN 1525:2007

Type of building/space	Category	Operative temperature ^{0}C	
		Minimum for heating (winter season), - 1.0 clo	Maximum for cooling (summer season), - 0.5 clo
Residential Buildings: living spaces	I	21.0	25.5
	II	20.0	26.0
	III	18.0	27.0
Office	I	21.0	25.5
	II	20.0	26.0
	III	19.0	27.0
Auditorium	I	21.0	25.5
	II	20.0	26.0
	III	19.0	27.0
Classroom	I	21.0	25.0
	II	**20.0**	**26.0**
	III	19.0	27.0
Kindergarten	I	19.0	24.5
	II	17.5	25.5
	III	16.5	26.0
Cafeteria/restaurant	I	21.0	25.5
	II	20.0	26.0
	III	19.0	27.0
Assumed clothing level for winter and summer (EN ISO 9920)			

2.1.3. Carbon dioxide

Indoor air quality can be categorized by CO_2 concentration. Carbon dioxide is a good indicator for the emission of human bio effluents. Standards take into consideration the human metabolism as well as typical emissions in low-pollution buildings – also the case of this research.

Default values for indoor air quality categorized by CO_2 concentration as given by standard ÖNORM EN 13779:2008 can be seen in Table 3 along with the classification of indoor air quality (IDA).

Table 3. CO_2 level in rooms – ÖNORM EN 13779:2008

Category	CO_2 - level above level of outdoor air in ppm	
	Typical range	**Default value**
IDA 1	≤400	350
IDA 2	400 - 600	500
IDA 3	600 - 1,000	800
IDA 4	>1,000	1,200

Basic classification of indoor air quality (IDA)

Category	Description
IDA 1	High indoor air quality
IDA 2	Medium indoor air quality
IDA 3	Moderate indoor air quality
IDA 4	Low indoor air quality

The values for indoor air classes can be given in national regulation. Values presented in ÖNORM EN 13779:2008 were used as default values in the present research. The exact definition of categories depends on the nature of the pollutant sources that are to be taken into account, and on the effects of theses pollutants. For example, pollutant sources may be:

- Localized in spaces or distributed through a building;
- Continuous or intermittent emitters;
- Emitters of particles (inorganic, viable or other organic) or gases/vapors (organic or inorganic).

The effects can be considered in terms of perception of air quality or of health effects. These effects may depend on the persons exposed, e.g. whether they are healthy adults, children or hospital patients.

2.1.4. Relative humidity

Humidity has relatively a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy, however, long-term high-humidity indoors may cause microbial growth, and very low humidity (15-20 %) may cause dryness and irritation of eyes and airways. The humidification of indoor air is usually not needed.

According to standard ÖNORM EN 13779:2008 a winter minimum for humidity should be 40% (22C) while the summer maximum not higher than 60% (26C).

If a humidification or dehumidification system is used, standard ÖNORM EN 15251:2007 gives the design values for dehumidification and humidification (Table 4). Usually it is needed only in special buildings like museums, some health care facilities, etc.

Table 4. Recommended design criteria for the humidity in occupied spaces ÖNORM EN 15251:2007

Type of building/space	Category	Design relative humidity for dehumidification, %	Design relative humidity for humidification, %
Spaces where humidity criteria are set by human occupancy. Special spaces (museums, churches etc.) may require other limits	I	50	30
	II	**60**	**25**
	III	70	20

2.2. Selected libraries

2.2.1. Academy of Fine Arts Library

First mentioned in records in 1692, the Academy of Fine Arts is the oldest art college in Middle Europe. The library, however, is not documented prior to 1773 and the draft of the articles of the k.k. Akademie der vereinigten Bildenden Künste.

The library's stock of media included: books, hand drawings, copper engravings, photographs and magazines. The university library builds a bridge between the Academy and the public. It offers information and a work space to researchers, teachers and students - a center of communication on arts and science.

Figure 1. *Academy of Fine Arts, Schillerplatz*

In 1871 the Academy received the approval for the construction of the new building in Schillerplatz after plans by Theophil Hansen (current location of the library – Figure 1). In 1877 the festive opening of the new building in the presence of Emperor Francis Joseph I. Anselm Feuerbach, among others, was commissioned with its interior decoration, which was completed in 1892 (AFA 2012).

2.2.2. Vienna University of Technology Library

Vienna University of Technology Library was founded in 1815. The library service is currently on four sites: the Main Library (Figure 2) and three department libraries: the Chemistry Library, the Mathematics and Physics Library and the Urban Design Library. The Library also acquires catalogues books for the institutes of the Vienna University of Technology.

The collection Vienna University of Technology Library contains more than 1 million books, around 1500 scientific journals, a textbook collection, a reference collection, Austrian and German standards, and theses of the University. The focus is on science and technology, including related subjects. Most of the printed works (books, journals) are kept on open access shelves in the Library's reading rooms.

Figure 2. *Vienna University of Technology Library, Resselgasse 4*

The Main Library building was designed by the architects Justus Dahinden, Reinhard Gieselmann, Alexander Marchart, Roland Moebius & partners. The construction was completed in 1987 and it features owl sculptures by the Swiss artist Bruno Weber on the facade. The Main Library has six floors of open access areas and reading rooms, with around 700 study desks (TU 2012).

2.2.3. University of Vienna Library

The University Library of University of Vienna has the Main Library and 50 departmental libraries in various locations throughout Vienna. The research is going to be concentrating on the two reading rooms located in the Main Building at Dr.-Karl-Lueger-Ring 1.

The history of Vienna University Library has always been closely linked to that of Vienna University, starting with the foundation of the library in the year 1365, which makes it the oldest university library in the German-speaking area.
In 1884, the library followed the university into the new building where it is today. The library flourished for a while, until World War I put a sudden end to it: staff shortages due to the war, the economic crisis and an inconsistent acquisition policy, particularly concerning foreign journals, all took their toll. During World War II, the books were relocated to bomb shelters in Lower Austria, but many books were lost or damaged during. In 1951, the reconstruction of the damaged university building was complete; the large reading room's floor had been raised to gain room for extra space (Figure 3) (UW 2012).

Figure 3. *University of Vienna Library, Dr.-Karl-Lueger-Ring 1*

2.2.4. University of Veterinary Medicine Library

Since 1777 the location of the University of Veterinary Medicine was in Vienna's third district, and the idea of moving came shortly before the First World War. Many plans were made and rejected, wars and crises came along, but finally in 1996 the new campus was built in the "Danube area" in Vienna's 21st district (Figure 4).

Figure 4. *University of Veterinary Medicine Library, Veterinärplatz 1*

The University of Veterinary Medicine Vienna campus is now unique in Austria. The library building has a basic square form with a lateral length of 36 meters and an interior space of 18000 cubic meters. There are three floors (basement, ground floor, upper floor) with an effective area of 2624 m^2, as well as a “reading garden” on the roof (480 m^2). The library’s open access area comprises 2050 m^2, whereas there are 390 m^2 for closed stacks and 250 m^2 for offices and administrative rooms. As the present stock of books covers 4300 meters this means – under the assumption of a similar future growth rate – that this storage space will be sufficient for another 14 years (VET 2012).

2.3. Acquisition of data

The deployed method involved measuring temperature, relative humidity, carbon dioxide concentrations and light levels in the reading rooms of each of the four libraries throughout a period of ten months (May 2012 – February 2013). The chosen period thus includes data from both the cold and hot seasons.

Three types of measuring devices were used for the acquisition of data:

- HOBO U12 Temperature/Relative Humidity/Light/External Data Logger
- Vaisala Carbon Dioxide Transmitter
- Minolta Illuminance Meter

HOBO U12 sensors and Vaisala carbon Dioxide Transmitters were installed so that they would be protected from direct sunlight and other factors that would have influenced the readings. Each month the sensors were checked and read out using GreenLine software from Onset Computer Corporation (Figure 5).

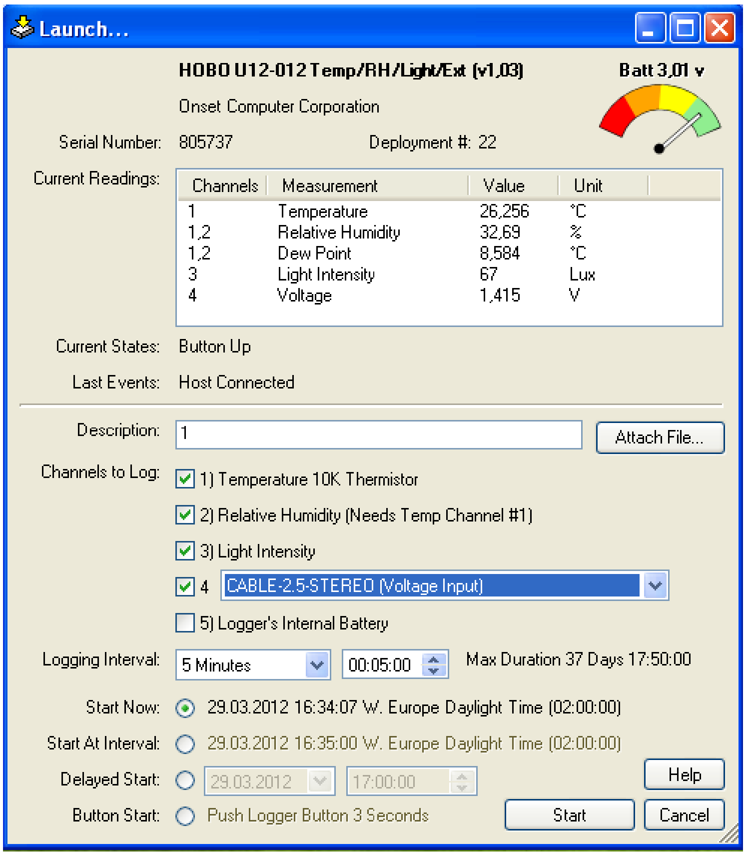

Figure 5. *GreenLine software – Screen shot*

2.3.1. HOBO U12

The HOBO U12-012 (Figure 6) accepts a wide range of energy and environmental sensors. It provides 12-bit resolution measurements for detecting greater variability in recorded data, and stores 43,000 measurements. Table 5 presents the sensor´s characteristics (Onset 2012).

Table 5. *HOBO U12*

Measures		Temperature, Relative Humidity, Light Intensity, Carbon Dioxide (connected to Vaisala CO_2 Transmitter)
Measurement Range		***Temperature***: -20° to 70°C
		RH: 5% to 95% RH
		Light intensity: 1 to 3000 foot-candles (lumens/ft2) typical
Accuracy		***Temperature***: ± 0.35°C from 0° to 50°C
		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
		External input channel : ± 2 m V ± 2.5% of absolute reading
Operating Environment		Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)
		Launch/readout: 0° to 50°C
Dimensions		58 x 74 x 22 mm
The CE Marking identifies this product as complying with all relevant directives in the European Union (EU)		

Figure 6. *HOBO U12*

2.3.2. Vaisala Carbon Dioxide Transmitter

The Carbon Dioxide transmitters (Figure 7) are versatile and ideal for demand controlled ventilation and related applications. They are available as both wall and duct mount models:

- Stable in terms of time and temperature
- Dust, water vapor or most chemicals do not affect the measurement accuracy of the sensor
- Small size enables easy integration into various systems

The characteristics of the model used in this research are presented in Table 6 (Vaisala 2012).

Table 6. Vaisala Carbon Dioxide Transmitter

Measures	Carbon dioxide
Measurement Range	0 ... 2000 ppm (nominal; can be calibrated for other ranges: 0 ... 5000 ppm, 0 ... 10,000 ppm, 0 ... 20,000 ppm)
Accuracy	± 2 % of range + 2% of reading - including repeatability, non-linearity and calibration uncertainty
Operating Environment	Temperature: -5 ... +45 °C (+23 ... +113 °F)
	Humidity: 0 ... 85 %RH, non-condensing
Dimensions	72 x 74 mm
Electromagnetic compatibility EN61326-1, Generic Environment	

Figure 7. *Vaisala CO_2 Transmitter*

2.3.3. Minolta Illuminance Meter T-10

The Minolta T-10 (Figure 8) is a multi-function digital illuminance meter with detachable receptor head. It is used for taking illuminance measurements and evaluations (Table 7). This illuminance meter is capable of calculating and displaying the average values of illumination (Konica Minolta 2012).

Table 7. Minolta Illuminance Meter T-10	
Measures	Illuminance (lx). Illuminance difference (lx). Illuminance ratio (%). Integrated Illuminance (lx·h). Integration time (h). Average illuminance (lx).
Measurement Range	Illuminance: 0.01 to 299,900 lx; 0.001 to 29,990 fcd
	Integrated illuminance: 0.01 to 999,900 x 103 lx·h 0.001 to 99,990 x 10*3 fcd·h / 0.001 to 9999 h
Accuracy	±2% ±1 digit of displayed value
	Temperature/ humidity drift: Within ±3%
Operating Environment	Temperature: -10 to 40°
	Relative humidity: 85% or less (at 35°C) with no condensation
Dimensions	69 x 174 x 35 mm
Conforms to requirements for Class AA of JIS C 1609-1: 2006 Illuminance meters Part 1: General measuring instruments	

Figure 8. *Minolta T10*

2.3.4. Installation of sensors

In order to get accurate measurements of all the parameters needed for this research, one HOBO U12 sensor and one Vaisala CO_2 Transmitter were installed in each of the five targeted reading rooms. The sensors where placed near the centers of the rooms in the respective libraries as shown in the following Figures.

In the Academy of Fine Arts Library the sensors were placed on a wooden bookshelf at a height of 2 meters (Figure 9). It was insured that that particular part of the shelf was not to be used by students. Figure 10 shows the exact location of the HOBO U12 and Vaisala Carbon Dioxide Transmitter location (circled in red).

Figure 9. *Academy of Fine Arts Reading Room*

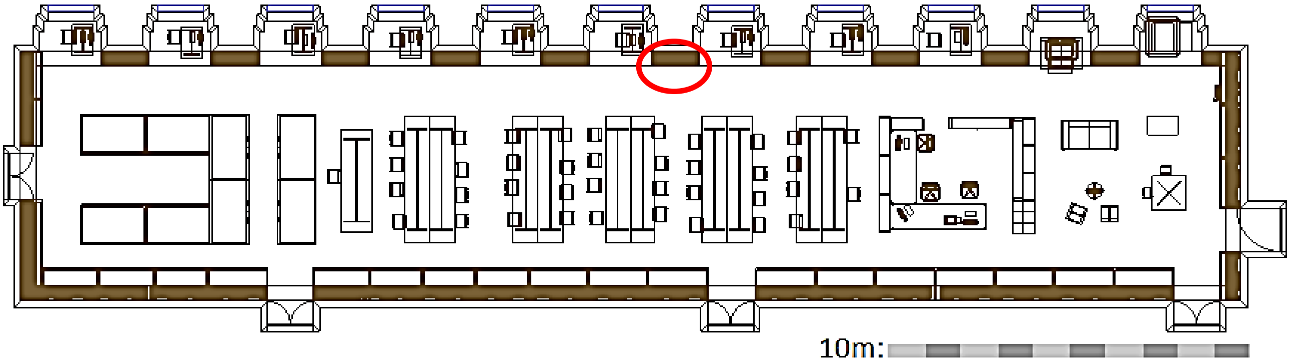

Figure 10. *Academy of Fine Arts Reading Room – Floor plan*

In the Vienna University of Technology´s Library the placement of the two sensors was chosen to be on a column padded with wooden panels in the center of the reading area on the fifth floor of the library as can be seen in Figure 11 and Figure 12.

Figure 11. *Vienna University of Technology Reading Room*

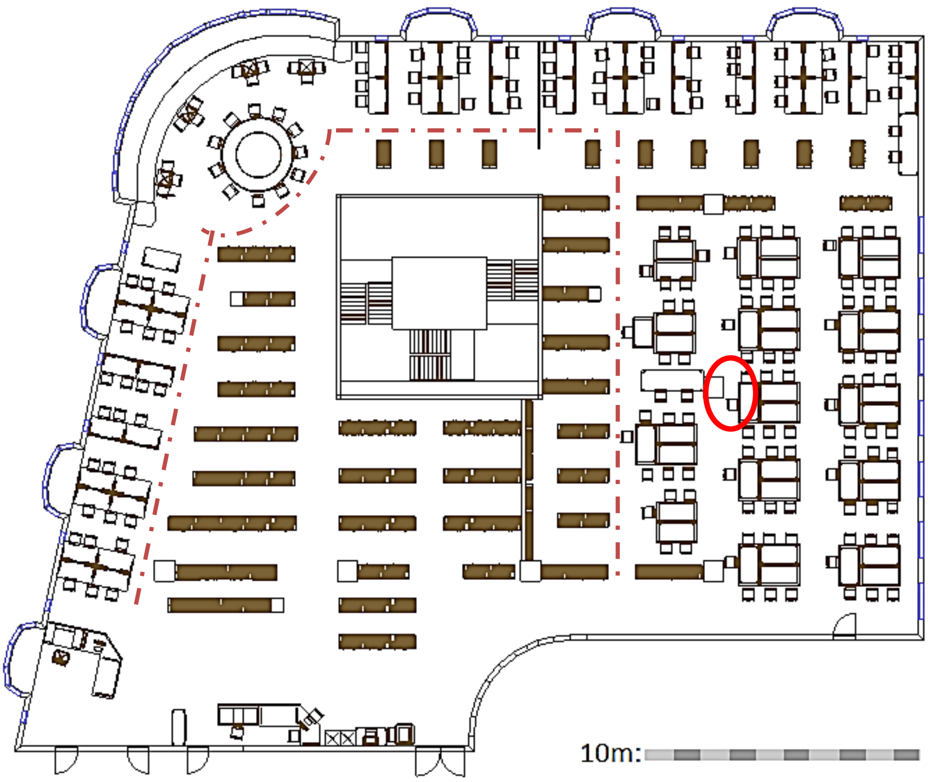

Figure 12. *Vienna University of technology Library–floor plan*

In the small reading room of University of Vienna´s Library the sensors were positioned on the outer wall on a plastic casing for cables at a height of 1.8 meters (Figure 13 and Figure 14).

Figure 13. *University of Vienna – Small reading Room*

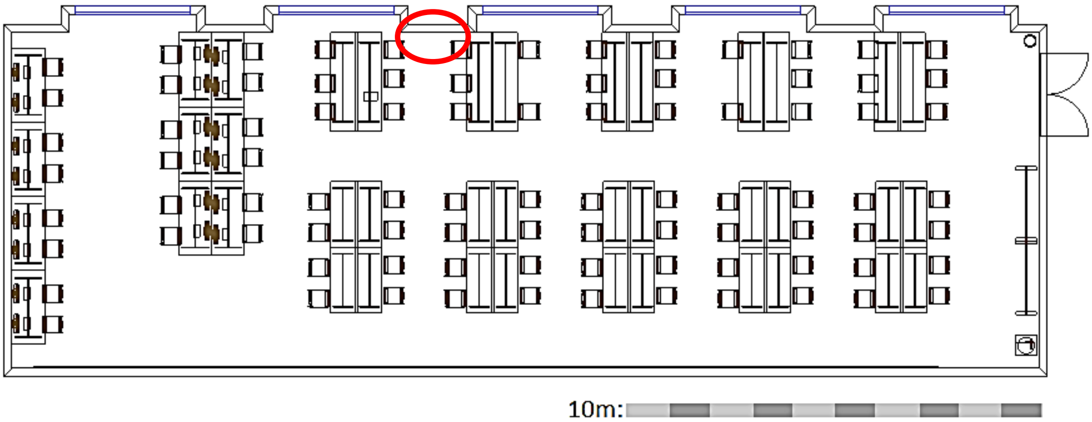

Figure 14. *University of Vienna – Small reading Room – floor plan*

In the University of Vienna´s Library – Large reading room, the sensors were placed on a concrete column at a height of 2 meters, as displayed in Figure 15 and Figure 16. The room has no windows but a skylight that is translucent and at over 7 meters high, therefore the readings from the Hobo and Vaisala sensors were not influenced.

Figure 15. *University of Vienna – Large Reading Room*

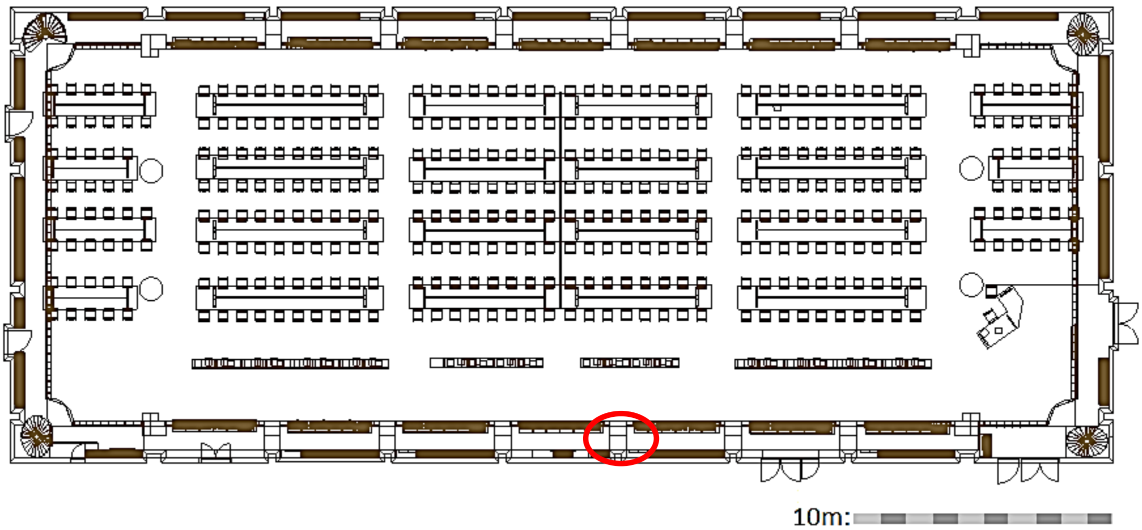

Figure 16. *University of Vienna – Large Reading Room – floor plan*

For the University of Veterinary Medicine Library, the reading area on the ground floor of the building was chosen to be analyzed. The sensors were put on a concrete wall at a height of 1.8 meters (Figure 17 and Figure 18).

Figure 17. *Veterinary University Reading Room*

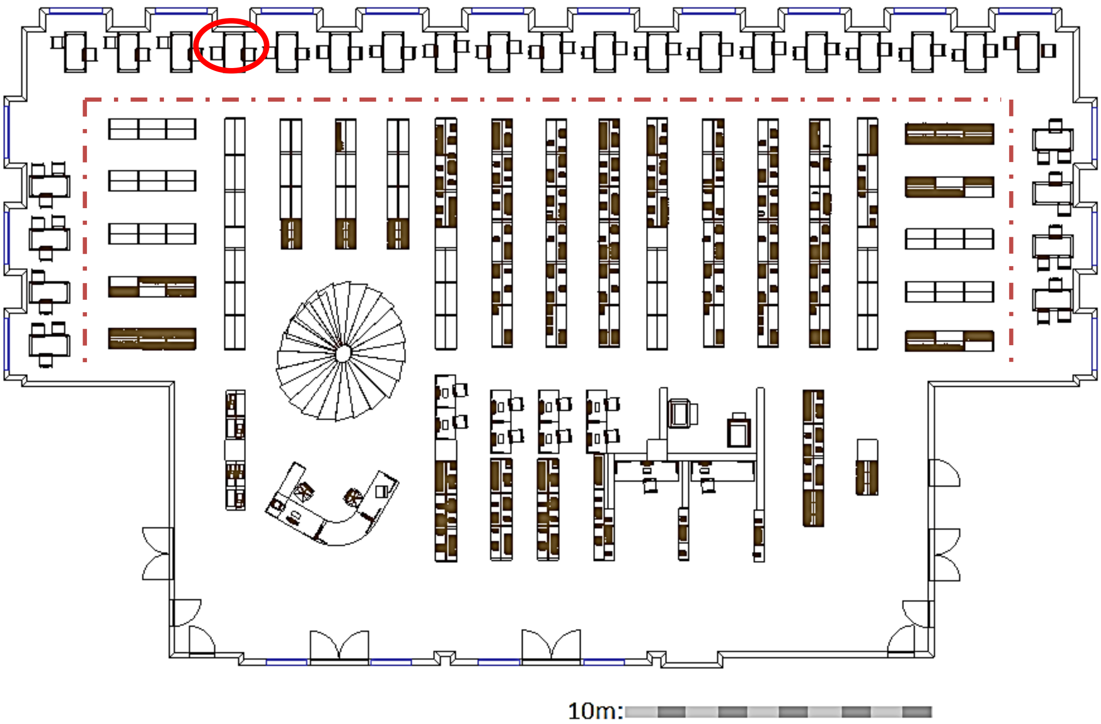

Figure 18. *Veterinary University Reading Room – floor plan*

The HOBO U12 sensors that measure temperature, humidity and light levels, where placed in proximity to windows due to the arrangement of the reading areas, and because this research does not analyze daylight properties, the data from the HOBOs concerning light levels will not be analyzed.

For an exact reading of the illuminance levels on the task area (reading table), the Minolta T10 Illimuninance Meter was used. Measurements ware undergone at night time so that daylight would not be an influencing factor.

The Illuminance meter was placed on tables throughout the reading areas (Figure 18), where standards give the values for the lighting criteria. The Illuminance meter measures light levels in Lux [lx]. Lux is the unit for illuminance available at a certain location, in this case the surface of the book/notebook/paper that is being read.

Figure 19. *Minolta T10 set on a task area*

2.3.5. HVAC Systems

For a better analysis of the data that was acquired for temperature, relative humidity and carbon dioxide and the influencing factors for these parameters, information about the HVAC systems inside the four buildings is shown in Table 8.

Table 8. **HVAC Systems**

Reading Room	**Cooling System**	**Heating System**
AFA	Mixed Mode Ventilation*: -ceiling diffusers -window ventilation	Hydronic with radiators Electric
TU	Mixed Mode Ventilation*: -ceiling diffusers -window ventilation	Hydronic with radiators Forced-air System
UW S	Mixed Mode Ventilation*: -air supply and return diffusers -Window ventilation	Hydronic with radiators
UW L	Mixed Mode Ventilation*: -air supply and return diffusers	Forced-air System
VET	Mixed Mode Ventilation*: -ceiling diffusers -window ventilation	Hydronic with radiators

*Natural and Mechanical Ventilation

2.4. Yearly Weather Summary for Vienna

Vienna lies within a transition of oceanic climate and humid continental climate according to the Köppen classification.

Summer

Vienna goes through a warm summer with regular maximums of 22 to 26 °C. The high temperature may exceed 30 °C in some infrequent days while the low is around 15 °. Although Vienna receives a moderate level of precipitation throughout the year, summer is a bit wetter than any other seasons; especially June receives more than 70 mm of precipitation. The season has a great level of sunshine, more than eight hours, particularly during July and August.

Winter

Winter comes in November and lasts till February. The maximums can reach 7ºC during this time, although it often drops below freezing point. December witnesses not more than two hours of sunshine and receives around 44mm of precipitation. Moreover, snowfall often occurs to make the climate even harsher mainly from December through March.

Spring and autumn

During spring and autumn Vienna experiences a milder climate. Spring has average temperature around 15°C. However, nighttime temperature often falls to single digit. Generally, the city receives a very poor level of sunshine throughout the season. Frequently the weather may become unpredictable when the skies are overcast.

In Figures 20 and 21 monthly average temperatures, precipitations and Sun days are displayed according to the Central Institute for Meteorology and Geodynamics (1981 -2010) (ZAMG 2013).

Monthly average temperatures and rainfall for Vienna (198 m)	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Max. Temperature (ºC)	3,2	5,2	10,3	16,2	21,1	24,0	26,5	26,0	20,6	14,6	8,1	3,6
Min. Temperature (ºC)	-1,9	-1,0	2,4	6,3	10,9	14,0	15,9	15,7	11,9	7,3	3,0	-0,8
Temperature (ºC)	0,3	1,5	5,7	10,7	15,7	18,7	20,8	20,2	15,4	10,2	5,1	1,1
Precipitation (mm)	38	40	51	45	69	70	70	72	61	38	49	48
Hours of Sun (h/d)	2,2	3,6	4,6	6,6	7,7	7,9	8,5	8,1	6,1	4,3	2,2	1,7
Rain days (d)	8,1	7,6	8,9	6,9	9,0	9,3	8,7	8,8	7,4	6,3	8,1	8,7

Figure 20. *Annual Temperatures and Rainfall – Vienna (ZAMG)*

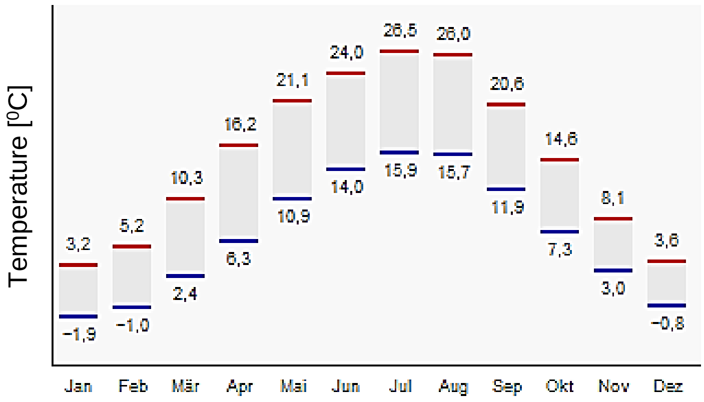

Figure 21. *Monthly averages (ZAMG)*

In order to get a better overview of the temperature fluctuation inside the targeted buildings, a Weather file for the years 2012 and 2013 for Vienna was provided for this thesis by the BPI Weather Station located on the roof of Vienna University of Technology.

In Figure 22 the location of all four libraries and the BPI Weather Station can be observed. The Academy of Fine Arts Library and Vienna University of Technology Library are both located within less than 0.5 km from the Weather Station while the other two libraries are located further away but still within a 10 km radius.

Figure 22. *Map of Vienna with the locations of the libraries (Google Maps)*

2.5. Type of Analysis

In order to make a thorough analysis of the data that was acquired multiple methods of analysis were undergone.

Histograms show the actual differences in temperature, carbon dioxide and relative humidity levels inside the five reading rooms. This type of graph shows frequency distributions defined as the amount of time in which a parameter (T, CO_2 and RH) was of a certain level/value.

2.5.1. PMV/PPD

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. Dissatisfaction can be caused by warm or cool discomfort of the body, as expressed by the PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied). The PMV can be used to check whether a given environment complies with comfort criteria. A PMV value equal to zero implies combinations of activity, clothing and environmental parameters that will provide on average a thermally neutral sensation (Szokolay 2004).

The PMV predicts the mean value of the thermal votes of a large group of people exposed to the same environment. But individual votes are scattered around this mean value and it is useful to be able to predict the number of people likely to feel uncomfortably warm or cool. The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm (ÖNORM EN ISO 7730:2006). Thermally dissatisfied people are those who will vote hot, warm, cool or cold on the 7-point thermal sensation scale given in Table 9.

Table 9. Seven point thermal sensation scale ÖNORM EN ISO 7730:2006	
+3	hot
+2	warm
+1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold

For the purpose of calculating PMV and PPD - temperature, relative humidity, air velocity, metabolic rates and clothing values were used as given by standard ÖNORM EN ISO 7730:2006 (Table 10).

Table 10. Parameters for calculating PMV and PPD

Parameter	Input (Summer)	Input (Winter)	Unit
Clothing	0.70	1.10	[0 to 2clo]
Air temp.	measured temp.		[10 to 30°C]
Mean radiant temp.	equal to measured temp.		[10 to 40°C]
Activity	1.2	1.2	[0.8 to 4met]
Air speed	0.19	0.16	[0 to 1m/s]
Relative humidity	measured RH		[30 to 70%]

To insure an easy read, a legend was created for the parameters that are frequently used as displayed in Table 11.

Table 11. Legend

Temperature	T
Relative Humidity	RH
Carbon Dioxide	CO_2
Academy of Fine Arts Library	AFA
Vienna University of technology Library	TU
University of Vienna Library - Small Reading Room	UW S
University of Vienna Library - Large Reading Room	UW L
University of Veterinary Medicine Library	VET
May	May
June	Jun
July	Jul
August	Aug
September	Sept
October	Oct
November	Nov
December	Dec
January	Jan
February	Feb

3. Results and Discussion

In this chapter the findings of this research are presented. The differences between the four libraries with respect to the measured parameters are identified and discussed. The HOBO and Vaisala sensors read data once every five minutes daily throughout the entire monitored period, but for the analysis only data from 8:00 AM to 18:00 PM was considered (working hours).

3.1. Light

Artificial light is installed onto the suspended ceilings in all of the reading rooms except UW L where lamps are installed on reading tables and onto book shelves. In Table 12 measured light levels are presented in comparison to the recommended values given by the standards. It can be observed that in two of the rooms, UW S and VET, the levels don´t meet the requirements. Inside AFA, TU and UW L there are areas where the 500 lux value is met and others where it is not – depending on the positioning of the lamps.

Table 12. Illuminance levels for all the libraries

Library	Working Area		
	Light Levels [lx] Table with lamp	Light Levels [lx] Table without lamp	Light Levels [lx] Book Stack
Academy of Fine Arts	500 - 700	100	40 -80
Vienna University of Technology	500 - 700	300 - 400	100-200
University of Vienna - Large Reading room	350 - 700	-	100-300
University of Vienna - Small Reading room	-	300 - 400	-
University of Veterinary Medicine	-	300 - 400	100-250
Recommended Values	500		200

Standards prescribe illuminance values to enable different tasks to be accomplished, including reading or finding a building exit. That does not guarantee good lighting design, which results from the artful balance of the various aspects of the quality of light and the avoidance of glare.

The factors that determine good functional lighting design in libraries include not only the amount of light energy available for specific visual tasks, but also the direction of the light relative to the eye, the brightness of objects surrounding the task object and within the field of view, and the surface reflectance and light-diffusing characteristics of the task object. An environment that largely achieves these ratios can be considered to have a good level of visual comfort (Dean 2005).

Due to the fact that for this research only illuminance levels were measured and not other influencing factors, a final conclusion cannot be drawn. Even so measurements showed that in some instances illuminance values were lower than the standard recommended ones thus affecting the visual comfort.

Further research into the visual discomfort is desirable through monitoring of brightness, reflectance and glare indicators.

3.2. Temperature

Given the fact that actual weather data for Vienna was made available, seasonal fluctuations in temperature are examined in reference to the inside temperatures and the reference temperature given by the standards. Because of changing outdoor conditions effects on the indoor temperatures can be seen in Figure 23.

It can be observed that starting with the end of May when outside temperatures started to rise above 20ºC, the temperatures inside the reading rooms also increased significantly, in most cases above the reference temperature of 26ºC. Throughout the summer season, inside temperatures remained above 26ºC and they started to decrease to an acceptable level mid-September when outside temperatures began to drop below 22ºC.

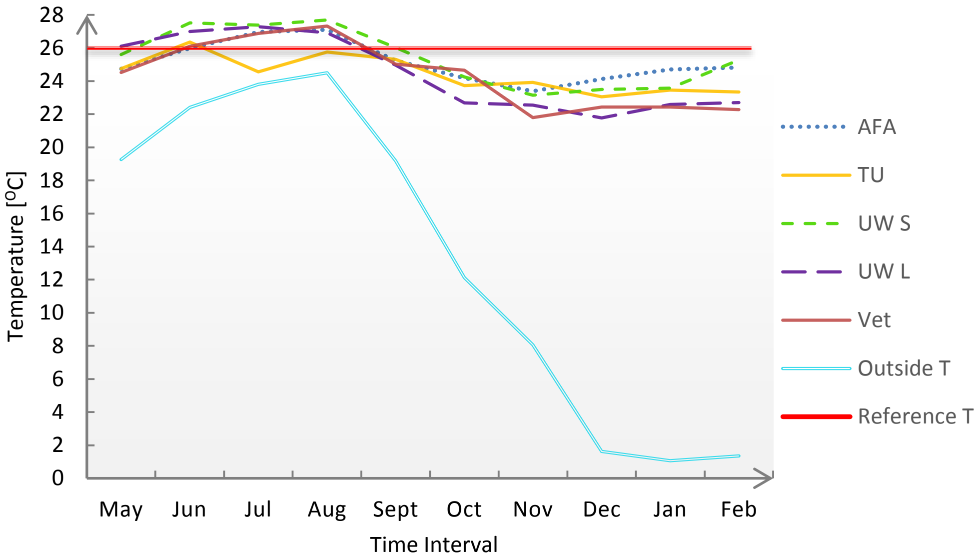

Figure 23. *Average Temperatures over a 10 month period*

The high inside temperatures where caused not only by the outside conditions, but also because of an increase in the number of students using the libraries during June and July coinciding with the exam period. End of July to mid-August the libraries were closed and so there was no ventilation during that period resulting in again high inside temperatures. The graph also reveals that after mid-September 2012 till the end of February 2013 the inside temperatures lay inside the acceptable limits and they never dropped below the standard accepted minimum of 20ºC.

After having a look at the average temperatures, for a more detailed analysis the actual inside temperatures are presented in the following ten Figures throughout the entire monitored period.

Figures 24 and 25 illustrate the inside temperature for the beginning of the summer season (May and June). In May inside temperatures in all the libraries fluctuated between 23 and 27^{o}C whereas in June they reached values of 28 up to 30^{o}C for 30-40 % of the time.

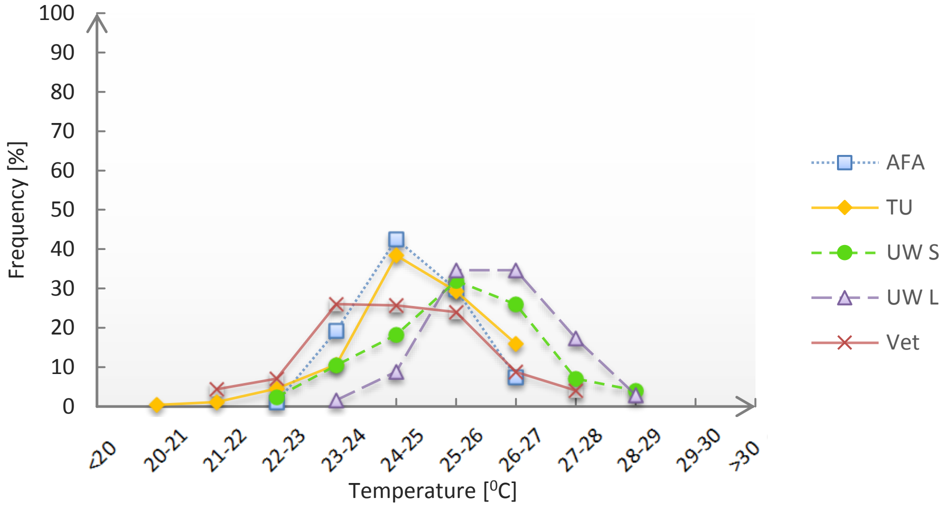

***Figure 24**. Inside Temperatures – May 2012*

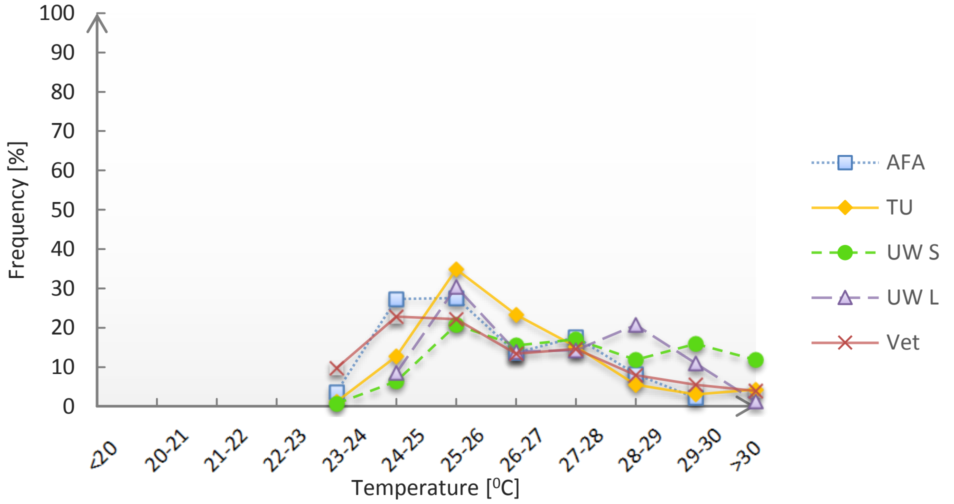

***Figure 25.** Inside Temperatures – June 2012*

July and August were the months with the highest temperatures, at times exceeding 30°C (Figure 26 and Figure 27). The variation of temperature in July during the working hours was in average within the 24-30°C interval. In August the temperatures fluctuated between 25 and 30°C.

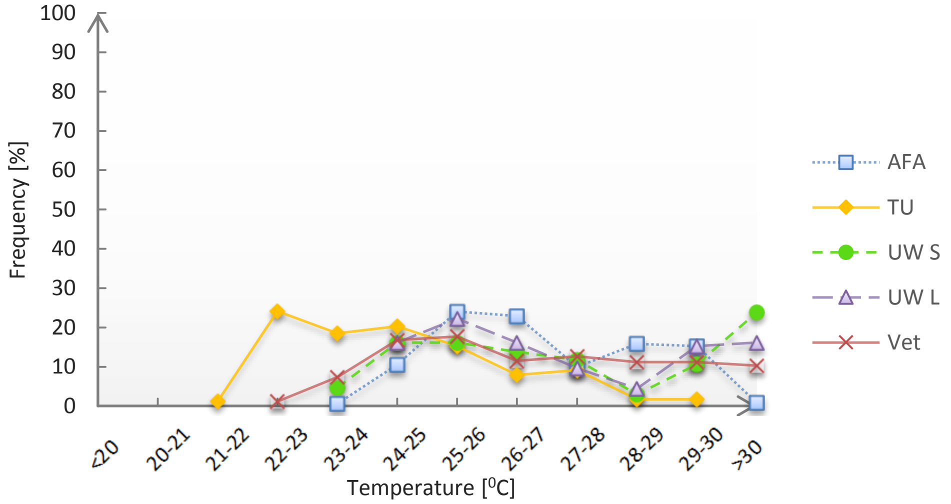

Figure 26. *Inside Temperatures – July 2012*

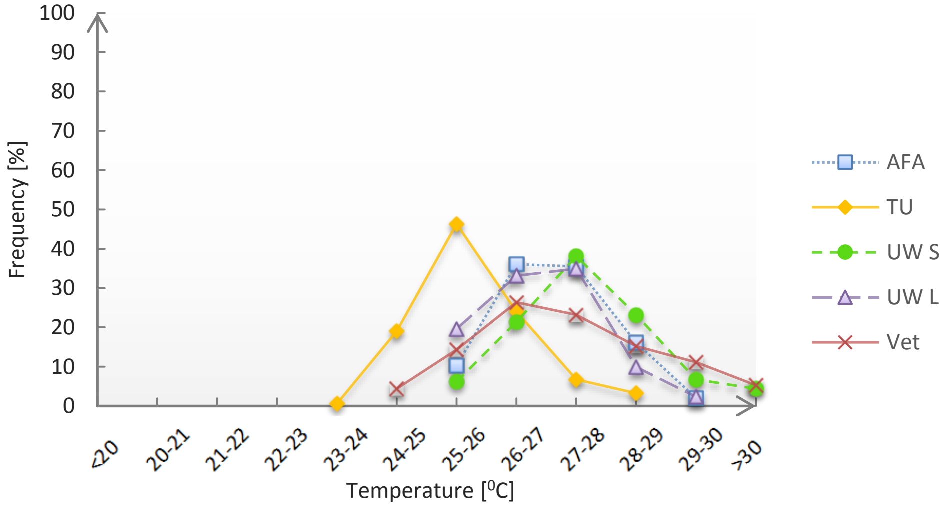

Figure 27. *Inside Temperatures – August 2012*

From September on (Figure 28) the inside temperatures started to decrease along with the seasonal changes and by the start of October (Figure 29) they were within the standard set limits. In September the inside temperatures were in average between 23 and 28°C and in October between 21 to 26°C.

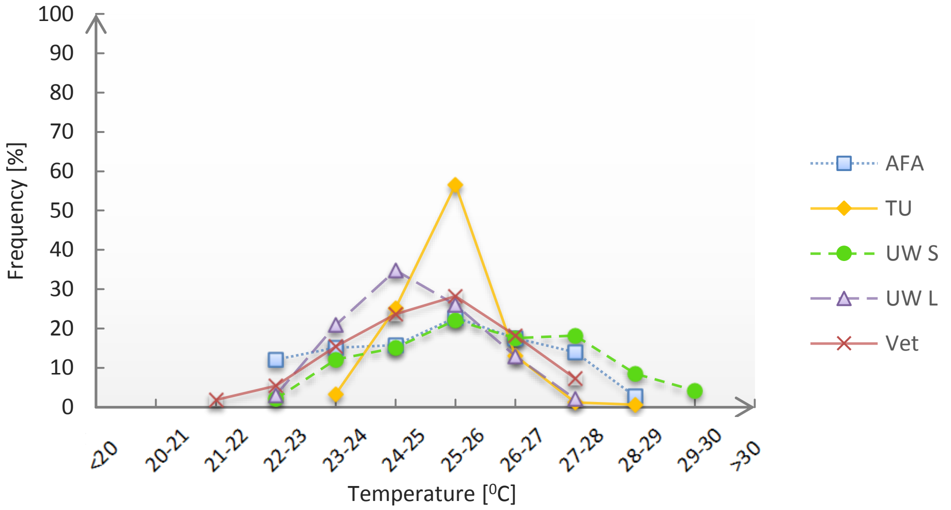

Figure 28. *Inside Temperatures – September 2012*

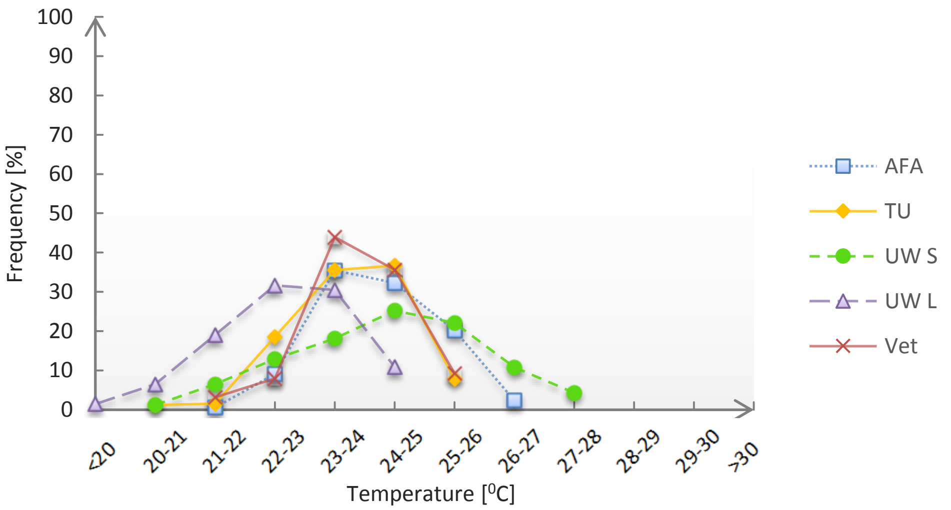

Figure 29. *Inside Temperatures – October 2012*

During the cold season, the temperatures inside the five reading rooms were within the 20-26°C standard recommended limits as shown in Figures 30 to 33, with few exceptions in the case of UW S which had temperatures of 27°C around 10% of the time in December, January and February (Figure 31, Figure 32 and Figure 33).

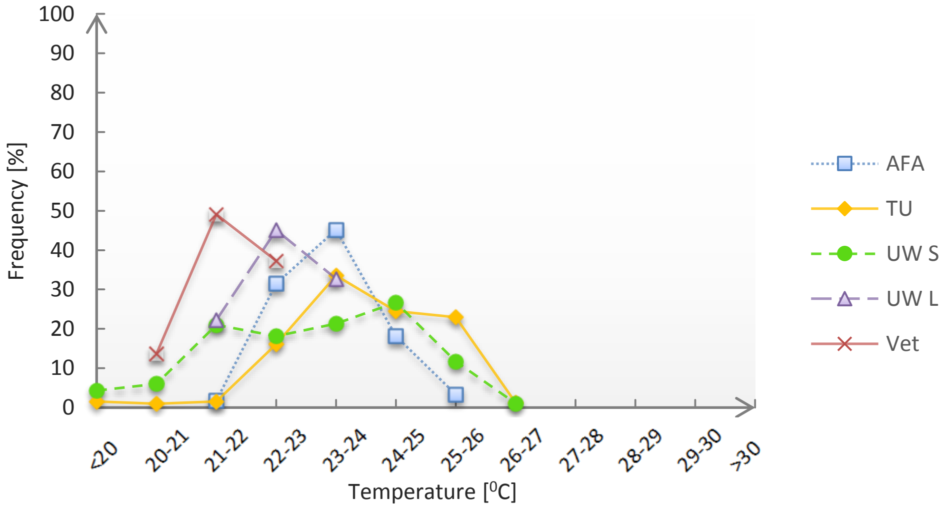

Figure 30. *Inside Temperatures – November 2012*

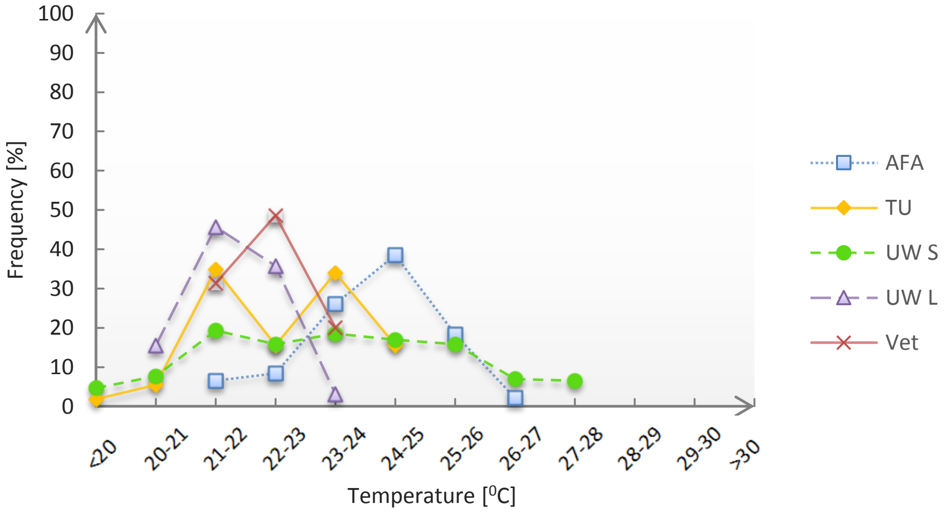

Figure 31. *Inside Temperatures – December 2012*

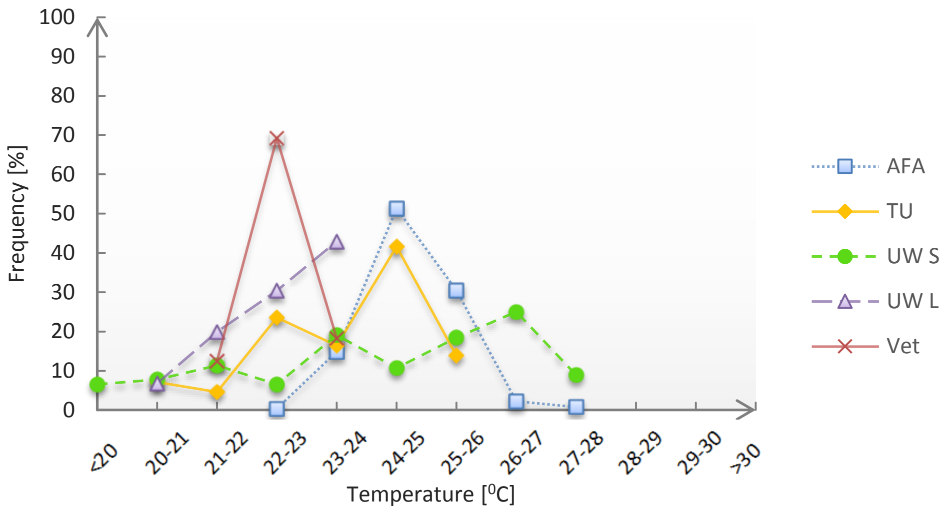

Figure 32. *Inside Temperatures – January 2013*

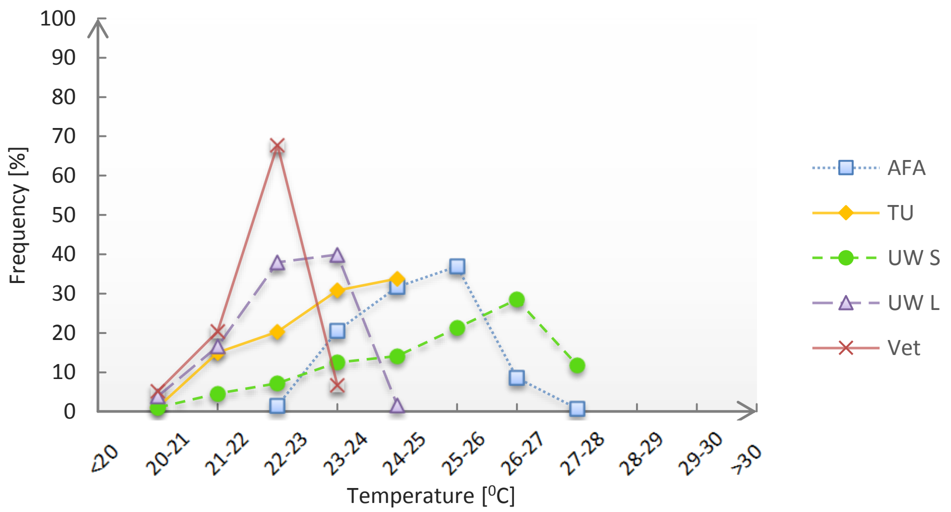

Figure 33. *Inside Temperatures – February 2013*

3.3. Carbon dioxide

Carbon dioxide is the by-product of human respiration and the burning of fossil fuels. It is a colorless, odorless gas that is heavier than air and at high concentrations it displaces oxygen. Therefor it is an important factor to be considered when analyzing air quality.

In Figures 34 to 43 frequencies of carbon dioxide concentrations are shown to determine to which IDA category the reading rooms correspond to.
Figures 34 and 35 show that in May and June the CO_2 concentrations inside the Vet are the only ones that remain for the entire month below 800 ppm situating the room in the IDA 2 category – Medium indoor air quality. The remaining four rooms were for almost 50% of the time in the IDA 3 category – Moderate Indoor Air Quality.

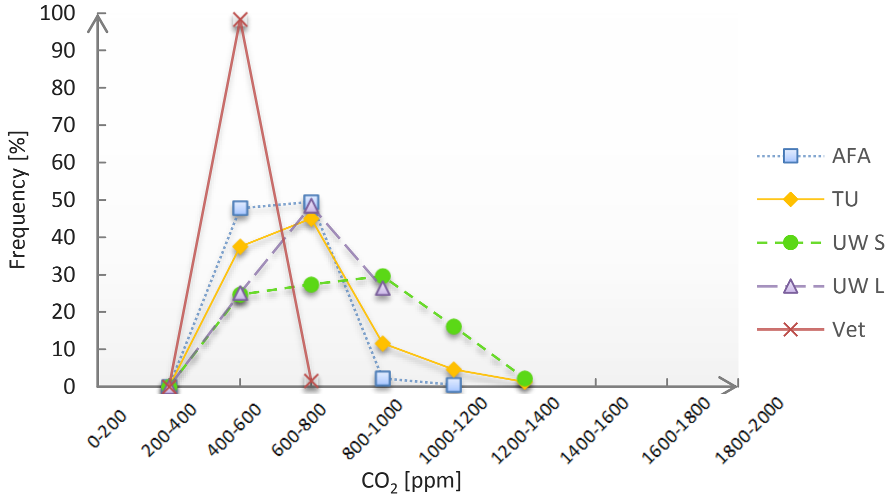

Figure 34. *CO_2 levels – May 2012*

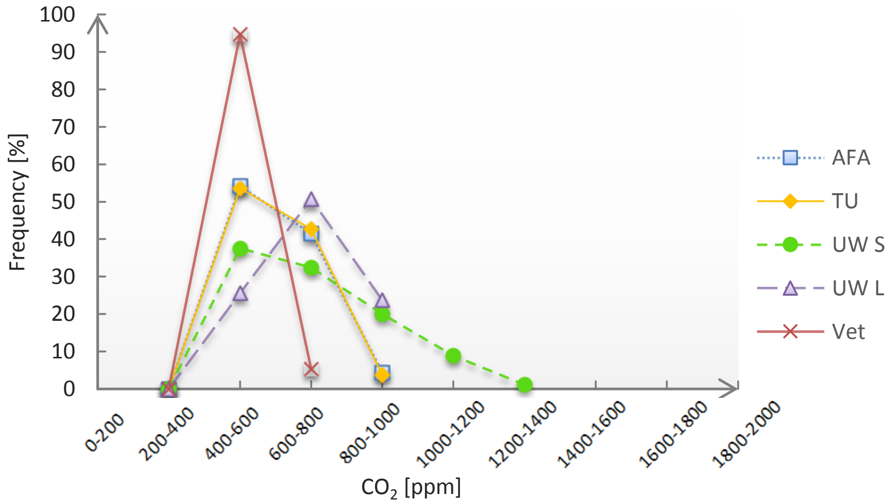

Figure 35. *CO_2 levels – June 2012*

In July and August due to the fact that natural ventilation was performed very often by students or library staff because of high temperatures, fresh air was brought inside the reading rooms throughout the day and so the CO_2 concentrations were lower than in the previous two months. The rooms can be classified in the IDA 2 category for 70% of the time and less than 30% in IDA 3 (Figures 36 and 37).

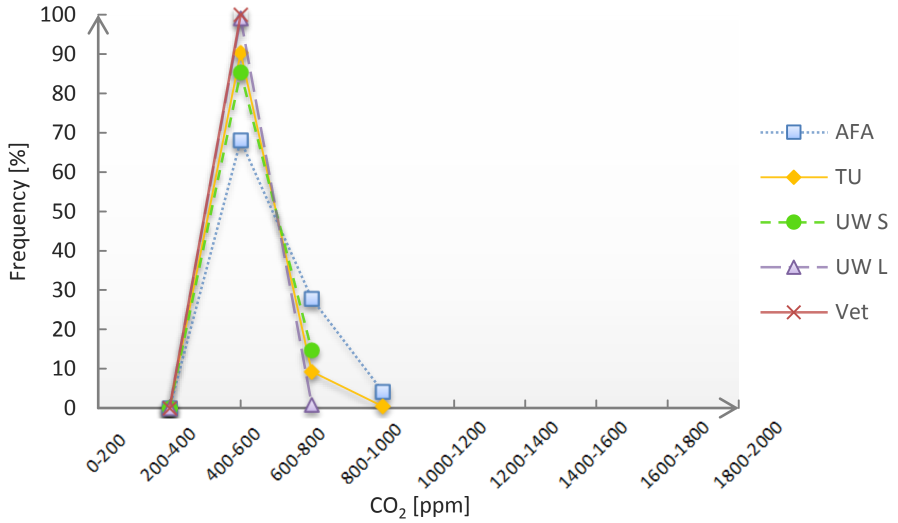

Figure 36. *CO_2 levels – July 2012*

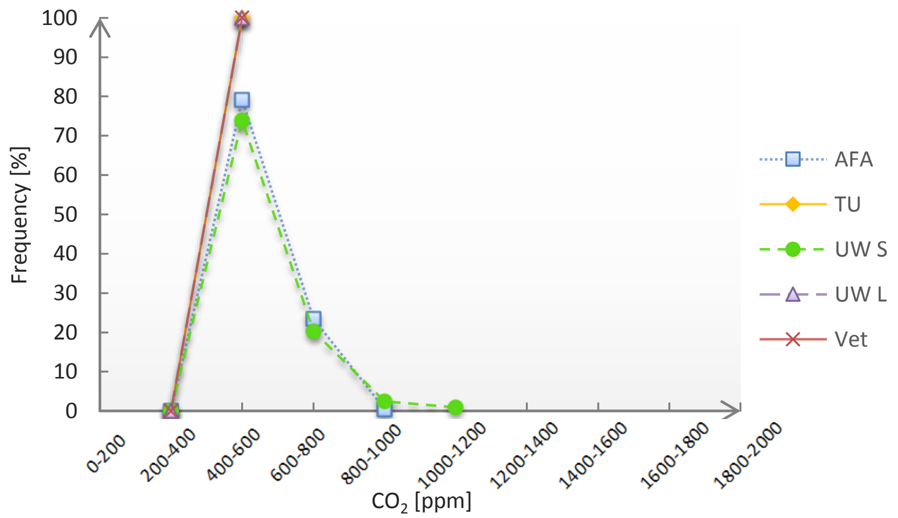

Figure 37*. CO_2 levels – August 2012*

Figures 38 to 42 show how due to the decrease in outside temperatures, natural ventilation was no longer performed thus resulting in a high increase of CO_2 concentrations throughout the Autumn and Winter seasons.

All of the libraries were in IDA 3 and IDA 4 categories during this time, with concentrations reaching at times 2000 ppm, except Vet which remained in the IDA 2 and scarcely in IDA 3 category for the entire period.

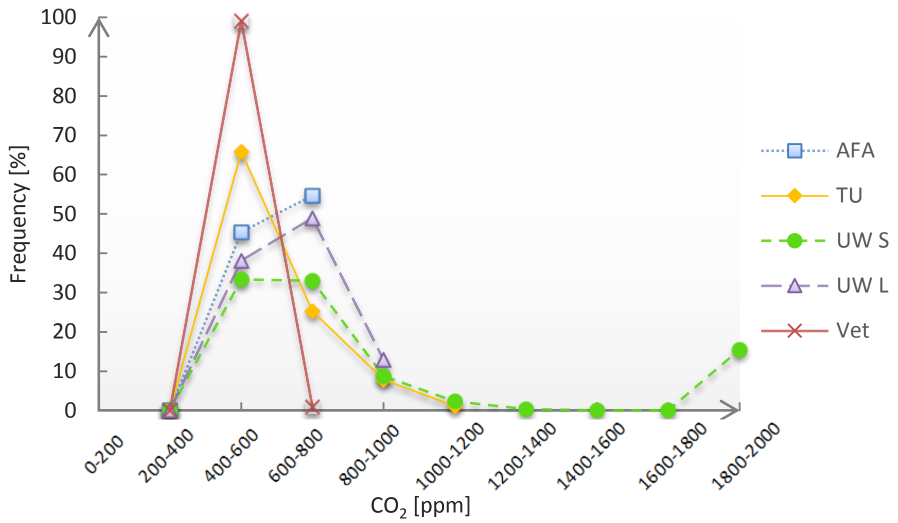

Figure 38. *CO_2 levels – September 2012*

As shown in Figures 38 to 42, the CO_2 concentrations inside TU and UW S were the highest ones when compared to the other reading rooms.

No upper CO_2 threshold has been defined by standards, nonetheless many researches have been done on this topic. Hutter et al. (2005) found that above levels of 1500 ppm people start to feel uncomfortable. Therefor it would be advisable to improve the ventilation systems so that the quality of air inside the reading rooms could rise to acceptable levels.

In October and November the CO_2 concentrations were between 400 and 1000 ppm. UW S had CO_2 levels reaching 2000 ppm almost 30% of the time (Figure 38).

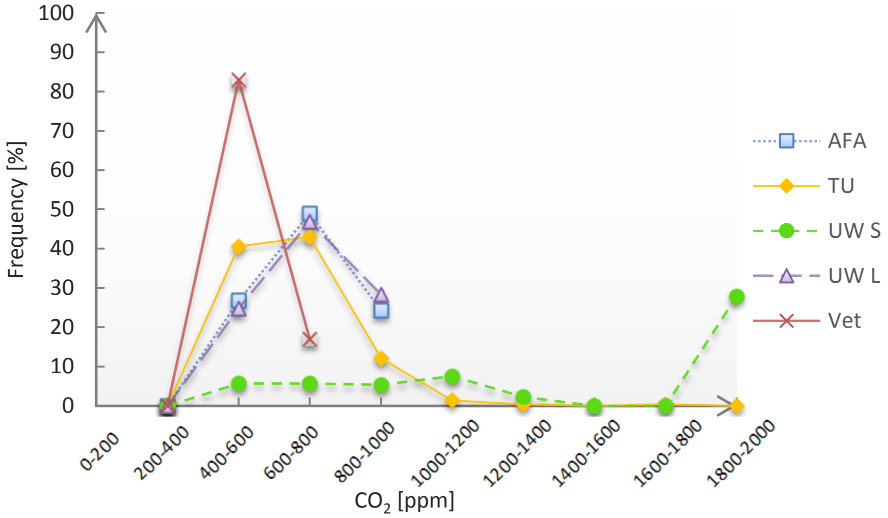

Figure 39. *CO_2 levels – October 2012*

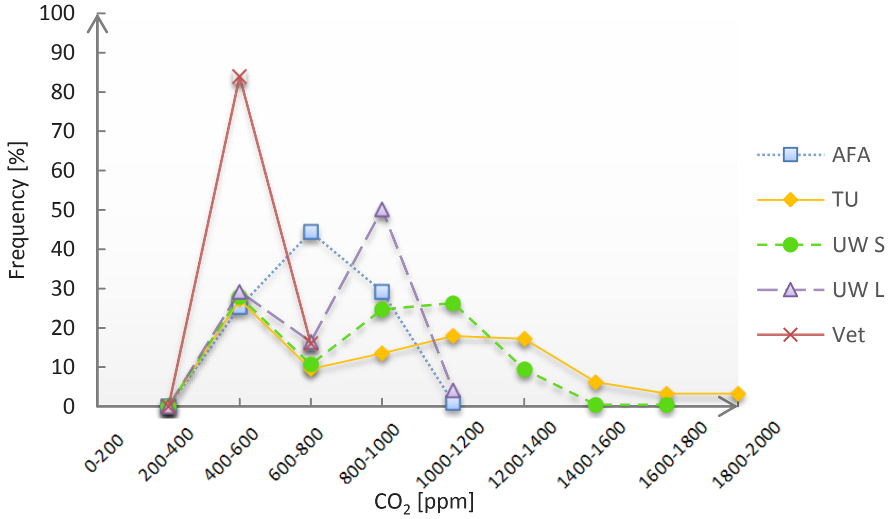

Figure 40. *CO_2 levels – November 2012*

In December AFA, UW L and VET all had CO_2 levels between 400 and 1000 ppm. Inside TU and UW S the levels were higher, up to 1600 ppm (Figure 41).

In January and February the concentrations varied between 600 and 1600 ppm for TU and UW S while for the remaining three rooms they were slightly lower, between 400 and 1000 ppm (Figure 42 and 43).

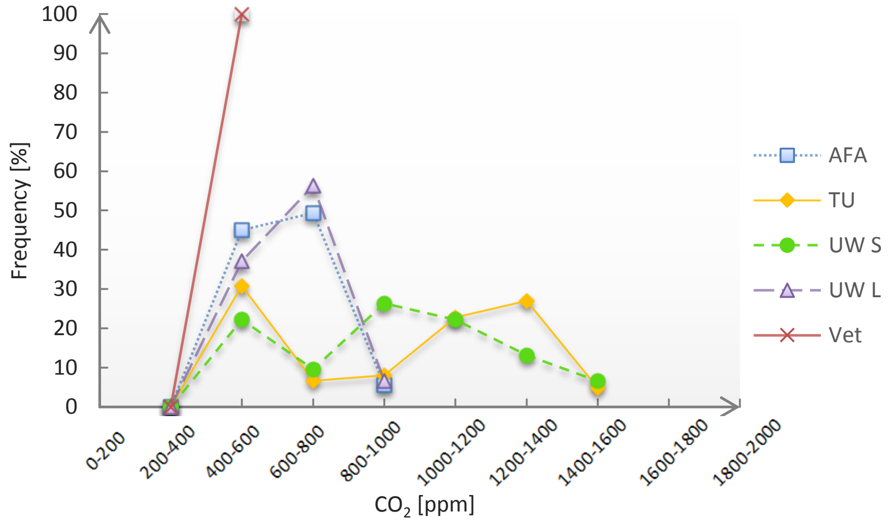

Figure 41. *CO_2 levels – December 2012*

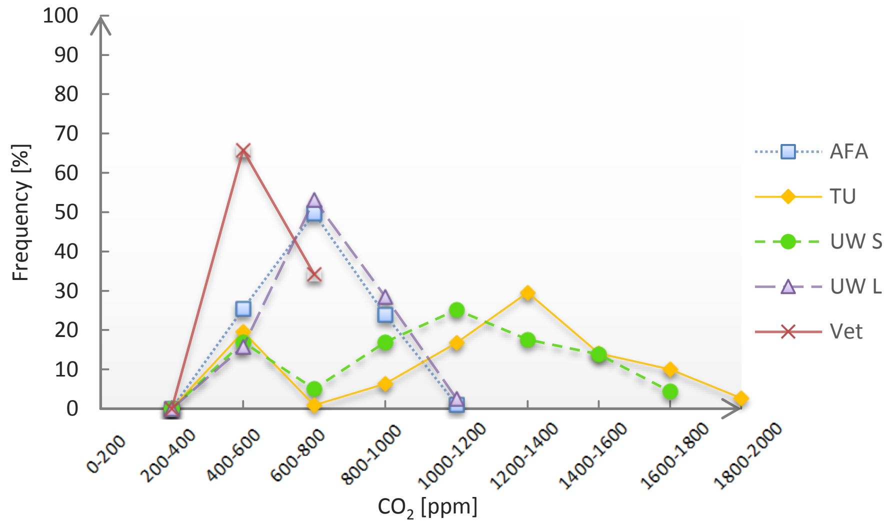

Figure 42. *CO_2 levels – January 2013*

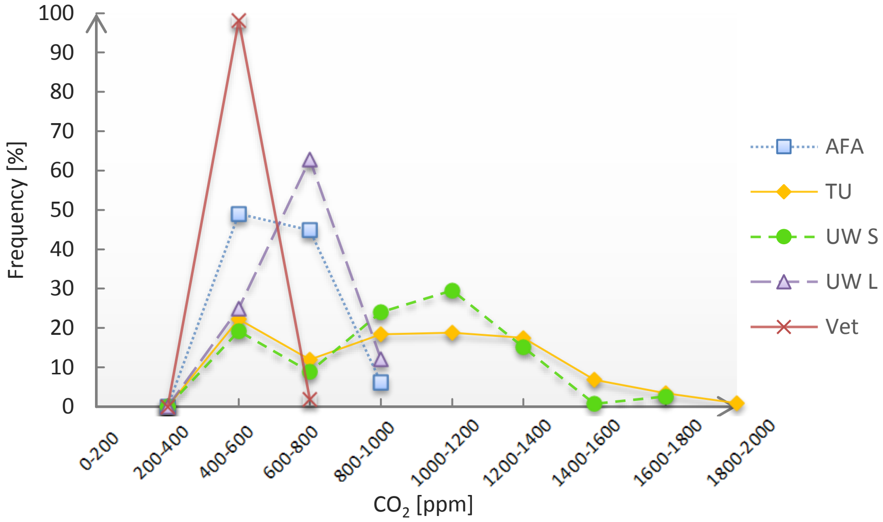

Figure 43. *CO_2 levels – February 2013*

High levels of CO_2 are usually associated with increased occupant discomfort and complaints of drowsiness, eye irritation, stale air and lack of oxygen. Since the present research did not analyze student behavior it cannot be stated at what CO_2 concentration these effects were or were not felt by the students inside the reading rooms. Future research could be centered on monitoring student behavior during the time spent inside the reading rooms.

3.4. Relative Humidity

Monthly cumulative frequencies of relative humidity levels are shown in Figures 44 to 53 for the purpose of identifying the differences between the five rooms.

Figure 44 illustrates that the RH in all the libraries drops below the 40% recommended value but less than 15 % of the time. According to Olesen (2006) 3-5% of the time (working hours) the calculated or measured values can be outside the range leaving only 10% of the month of May with low RH values.

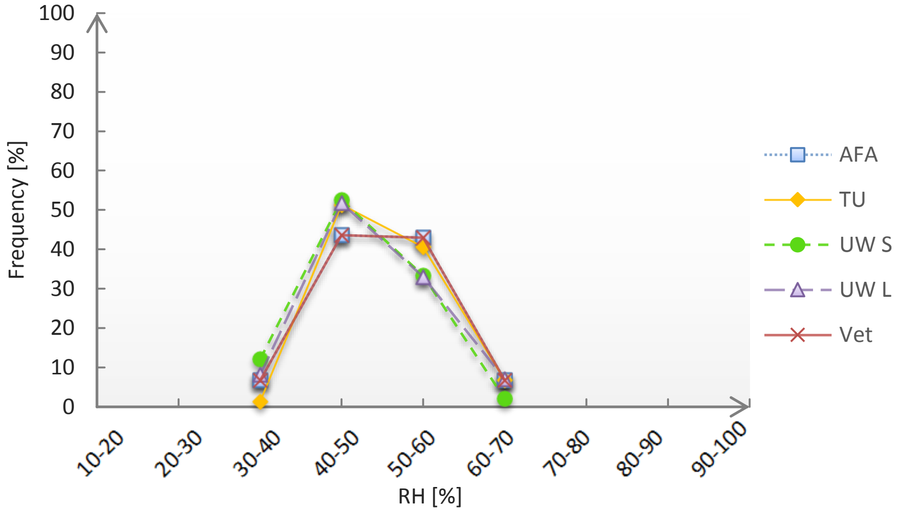

Figure 44. *Relative Humidity levels – May 2012*

Figures 44 to 49 show that RH values increased with rising outdoor temperatures in the warm season.

In June and August (Figure 45 and 47) RH was within the 40-60% recommended value limit and only in July it reached 80% for a few days inside UW S, UW L and VET (Figure 46).

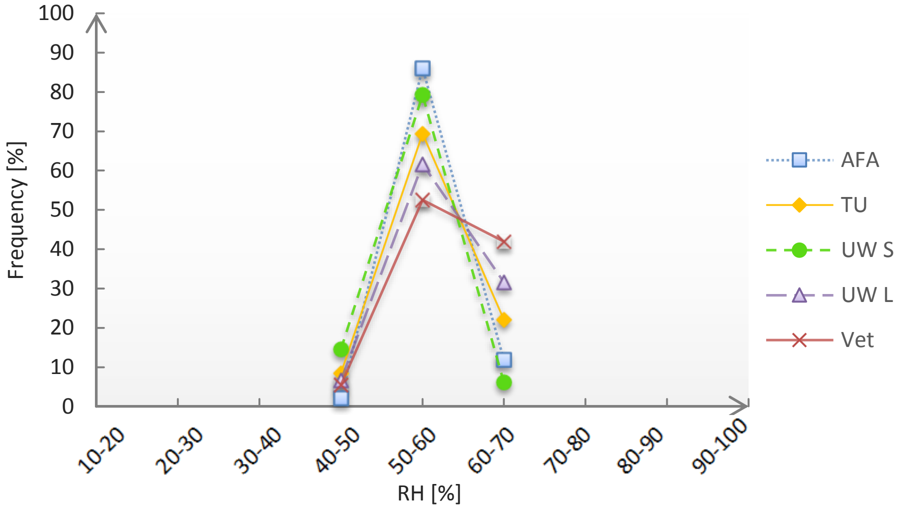

Figure 45. *Relative Humidity levels – June 2012*

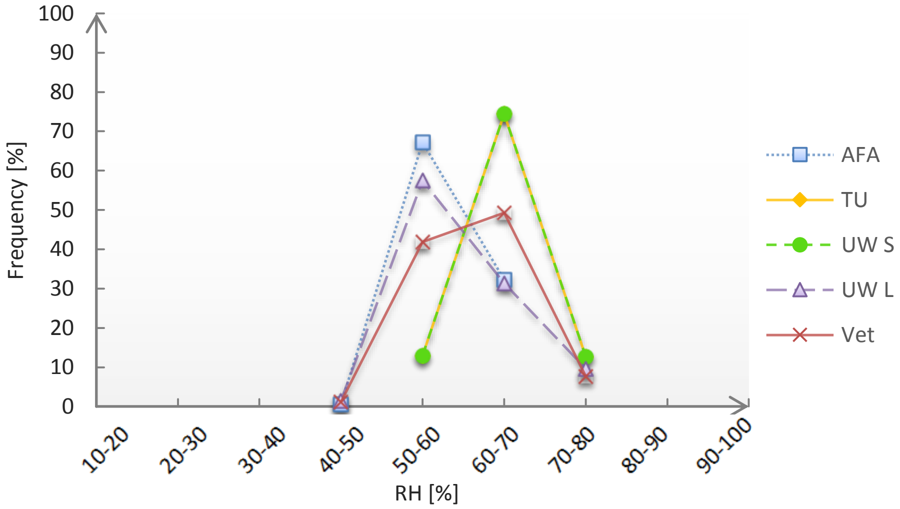

Figure 46. *Relative Humidity levels – July 2012*

During the autumn months (Figures 48 and 49) RH remained within the acceptable limits and started to slowly decrease in November (Figure 50).

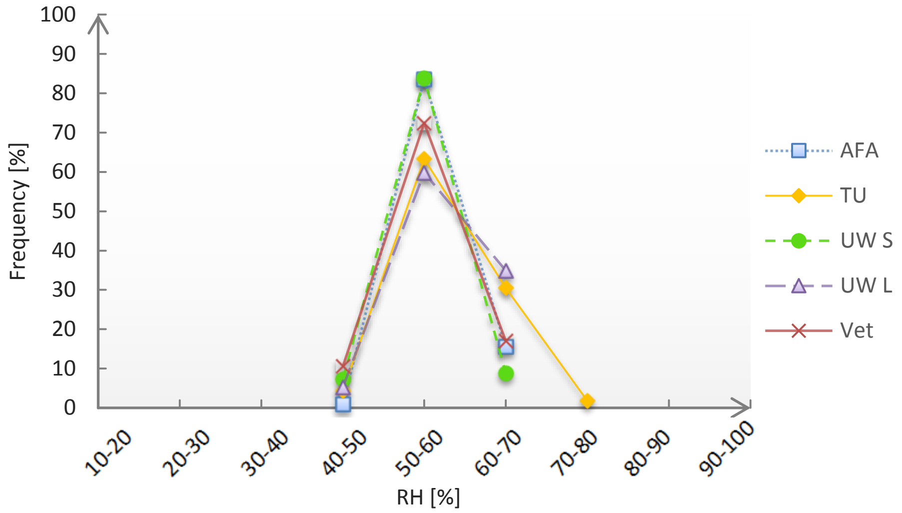

Figure 47. *Relative Humidity levels – August 2012*

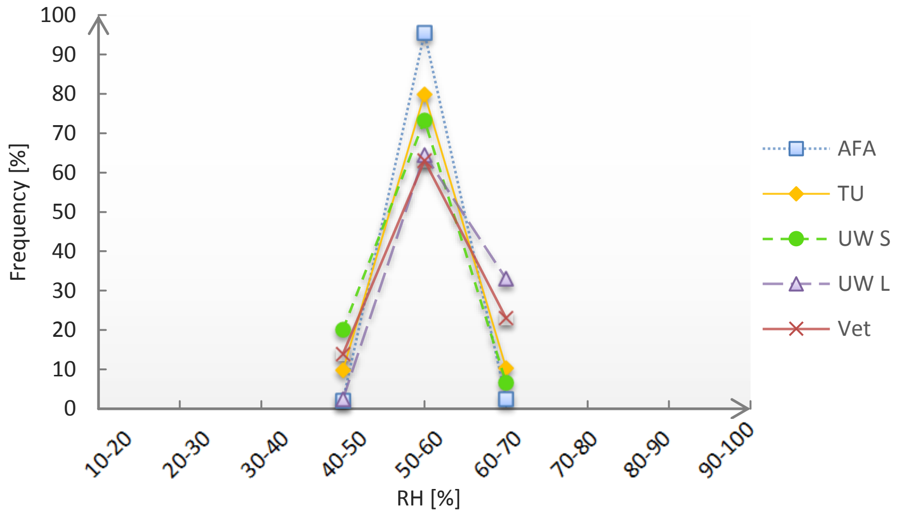

Figure 48. *Relative Humidity levels – September 2012*

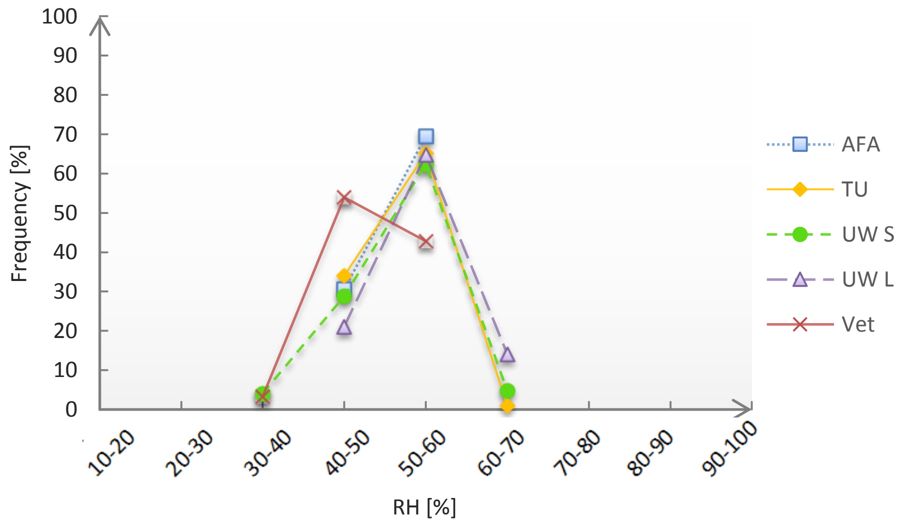

Figure 49. *Relative Humidity levels – October 2012*

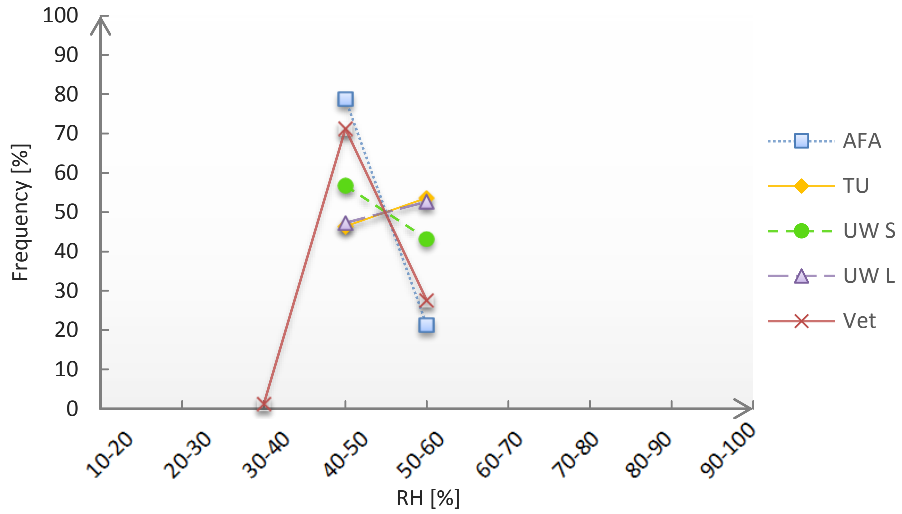

Figure 50. *Relative Humidity levels – November 2012*

In winter in particular, the RH was affected by the ventilation systems and once the rooms started to be heated the values started dropping (Figures 51, 52, 53). Therefor from December 2012 till February 2013 the RH dropped to values of 20% -30% and students might have had difficulties with the dry air during that time.

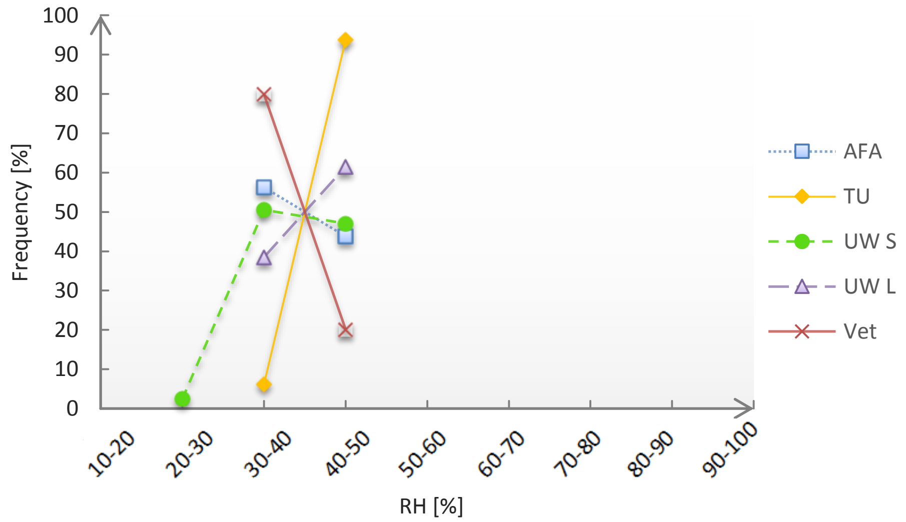

Figure 51. *Relative Humidity levels – December 2012*

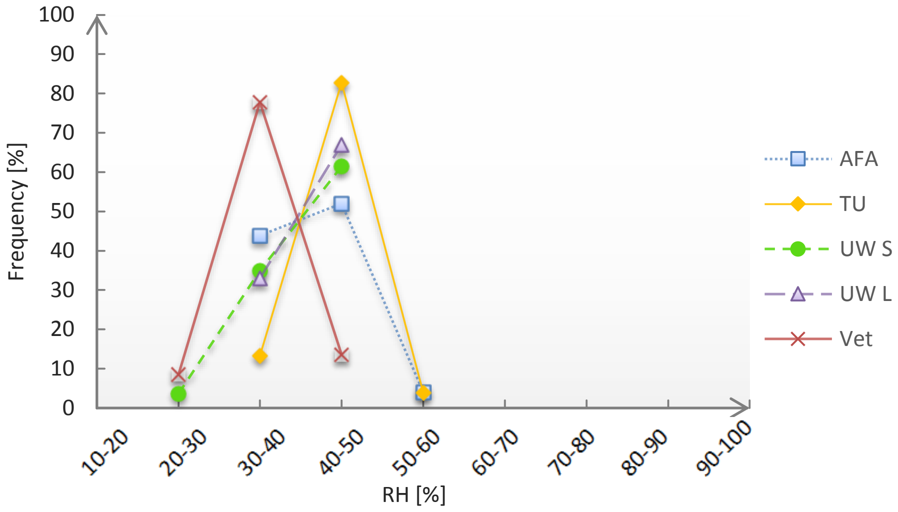

Figure 52. *Relative Humidity levels – January 2013*

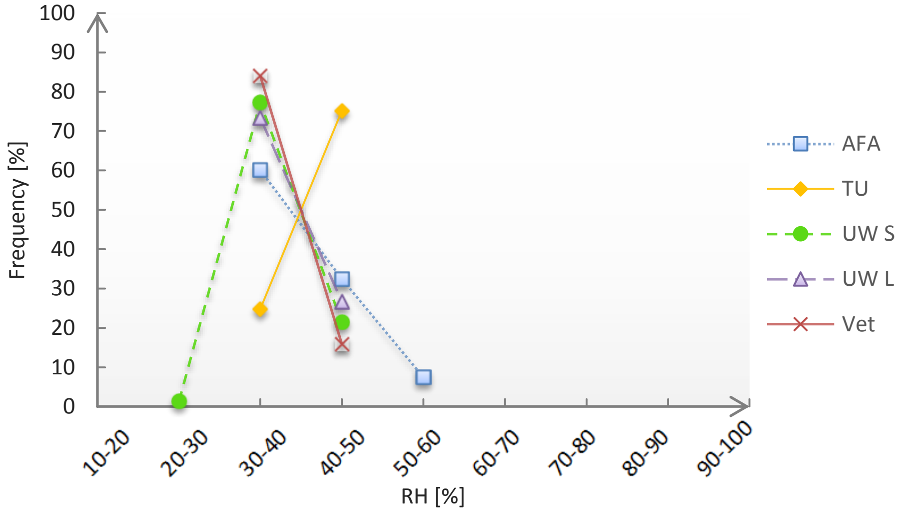

Figure 53. *Relative Humidity levels – February 2013*

According to Aizlewood (2002) there are three main causes that induce the high relative humidity in a space, namely ventilation, air conditioning equipment and building envelope problems. In the case of the four analyzed buildings it can also be observed that the ventilation system was one of the causing factors for the low levels of relative humidity during the cold season when the rooms were heated.

3.5. PPD and PMV

Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody, thus there will always be a percentage dissatisfied occupants. The PMV and PPD are used to determine different ranges of environmental parameters for the evaluation of the thermal comfort. PMV values between -0.5 and +0.5 corresponding to 12% PPD are considered comfortable. The PMV and PPD were calculated for each library for the entire monitored period.

3.5.1. Academy of Fine Arts Library

Table 13 summarizes calculated PMV and PPD values for AFA throughout the monitored period. AFA performed quite well throughout the hot and the cold season with values within the range of -0.5 to +0.5 PMV with corresponding 12% PPD. The only two months when the percentage of dissatisfied students was over 20% were July and August 2012. The reasons for the high values were the high temperatures of the summer season and the insufficient influx of fresh air.

Table 13. AFA

Time Period	PMV	PPD [%]
May-12	0.1	5.2
Jun-12	0.5	10.2
Jul-12	0.8	18.5
Aug-12	0.8	18.5
Sep-12	0.3	6.9
Oct-12	0.6	12.5
Nov-12	0.4	8.3
Dec-12	0.5	10.2
Jan-13	0.6	12.5
Feb-13	0.6	12.5

3.5.2. TU

Thermal comfort indices inside the TU were most optimum compared to the other four analyzed rooms. For the entire duration of the research PMV and PPD calculations showed that at all times the majority of students were comfortable with the indoor environment (Table 14).

Table 14. TU		
Time Period	**PMV**	**PPD [%]**
May-12	0.1	5.2
Jun-12	0.6	12.5
Jul-12	0.2	5.8
Aug-12	0.5	10.2
Sep-12	0.3	6.9
Oct-12	0.4	8.3
Nov-12	0.5	10.2
Dec-12	0.3	6.9
Jan-13	0.4	8.3
Feb-13	0.3	6.9

The reason why TU performed so well even in the summer season is because it is common for students to open the windows allowing the currents of fresh air to cool off the room. Also because of its orientation, the reading area on the fifth floor is harbored from direct sunlight.

3.5.3. UW S

PMV and PPD values calculated for UW S were the highest ones. This can be attributed to the small size of the room when compared to the others and its orientation. Table 15 illustrates PMV and PPD values for the ten monitored months inside UW S.

Table 15. UW S		
Time Period	**PMV**	**PPD [%]**
May-12	0.3	6.9
Jun-12	0.9	22.1
Jul-12	0.9	22.1
Aug-12	1.0	26.1
Sep-12	0.5	10.2
Oct-12	0.6	12.5
Nov-12	0.3	6.9
Dec-12	0.3	6.9
Jan-13	0.4	8.3
Feb-13	0.7	15.3

Compared to the other reading rooms for which the highest percentage of dissatisfied was calculated mainly for the summer months, UW S had high values of PMV and PPD for both the cold and the warm season. Thermal comfort was at low levels in June, July, August (26.1%) and February.

For the remaining six months out of the ten monitored, PMV and PPD values were within the comfort range which means that for almost half the time the thermal sensation inside UW S was improper for 20% of students causing discomfort and possibly affecting their work.

3.5.4. UW L

The UW L performed better than the UW S even though the two rooms are located on the same floor of the library building. The reasons for these considerable differences between the two are the dimensions of the rooms and the amount of glazing surfaces inside. Table 16 shows the PMV and PPD values for UW L.

PMV and PPD values started to increase with the beginning of the warm season. In June, July and August PPD was higher due to high temperatures and insufficient ventilation. For the remaining 7 months PMV was within the -0.5 and +0.5 values corresponding to 12% PPD.

Table 16. UW L

Time Period	PMV	PPD [%]
May-12	0.5	10.2
Jun-12	0.8	18.5
Jul-12	0.9	22.1
Aug-12	0.8	18.5
Sep-12	0.2	5.8
Oct-12	0.3	6.9
Nov-12	0.2	5.8
Dec-12	0.0	5.0
Jan-13	0.2	5.8
Feb-13	0.1	5.2

In December PMV values were equal to 0 which implies that during those that month the thermal comfort was of very high standards and only 5% of students were dissatisfied with the indoor environment.

3.5.5. Vet

The results for PMV and PPD for Vet were very satisfactory. Table 17 shows that in May the thermal comfort suited 95% of the occupants.

Throughout the cold season the PMV and PPD values were predominantly those of a good thermal comfort. Approximately 90% of the occupants of VET were satisfied with the indoor environment in eight of the ten monitored months. This can be attributed to the good ventilation system and the fact that the building and the equipment inside are less than 20 years old.

The only months when the predicted percentage of dissatisfied was greater than 12% were July and August. The high values can be attributed to the high temperatures of the summer season as in the case of the other analyzed reading rooms.

Table 17. VET

Time Period	PMV	PPD [%]
May-12	0.0	5.0
Jun-12	0.5	10.2
Jul-12	0.8	18.5
Aug-12	0.9	22.1
Sep-12	0.2	5.8
Oct-12	0.6	12.5
Nov-12	0.0	5.0
Dec-12	0.1	5.2
Jan-13	0.1	5.2
Feb-13	0.1	5.2

4. Conclusion and future research

The main goal of this research was to determine whether the indoor air quality and thermal comfort inside four of Vienna´s libraries befit the learning environment.

The evaluation was based on readings from sensors that were installed in the reading rooms of four university libraries for a ten months duration. The data that was acquired had approximately 600.000 entries for each of the chosen parameters: light, temperature, carbon dioxide and relative humidity.

Findings in this research suggest that high temperatures were the main factors to influence thermal comfort. During the summer months in all of the five analyzed rooms the inside temperatures reached at times 30°C which implies that the ventilation systems could not meet the requirements of comfort parameters for the indoor environment.

CO_2 concentrations were found to be high particularly in the cold season, at times exceeding levels of 2000 ppm, thus placing the rooms in the IDA 4 category – Low indoor air quality. Being exposed to high CO_2 levels can result in reduced ability to concentrate which impairs the learning experience overall.

Relative humidity was found not to have a big effect on the quality of the indoor environment. During the warm season relative humidity oscillated between 40 and 60 % and in winter it dropped to values of 20 to 30%. During the time when RH values were low students might have had difficulties with the dry air.

According to the PMV and PPD calculations thermal comfort was overall satisfying inside the five reading rooms. In the summer months the predicted percentage of dissatisfied was above 20% because of high outside temperatures that influenced the indoor conditions.

In order to better assess thermal comfort and the conditions inside the learning environments, future research should be done on a bigger scale. Health implications should also be looked into by analyzing the dust particulate matter, VOC levels, toxic gas matters and possibly other health influencing factors.

Analysis should be made on a larger number of libraries, preferably of different constructions years, materials and techniques to see to what extent the building itself influences the internal conditions. The monitored period should be extended to longer periods of time. Feedback from students should be taken into consideration since the human perception is one of the most determining factors when analyzing thermal comfort.

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6. Tables

7. Figures