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A Study of the Relationship between Thermal Comfort & Energy Consumption in Kindergartens

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Abstract

The purpose of the study is to determine if the thermal comfort in a kindergarten built to the Passive House standard shows improvements in thermal comfort levels and energy consumption when compared to one built to contemporary Austrian building regulations. Two case study kindergartens in Vienna were used. The kindergartens have similar occupancy, architectural programme, overall building volume, and building services.

Indoor environmental parameters, such as temperature and relative humidity, were measured in 20 rooms in the two kindergartens for a six month observation period. The rooms are divided into two categories: primary use spaces (classrooms), and secondary use spaces (kitchens, bathrooms, staff rooms, atria, and circulation spaces). Five classrooms per kindergarten were studied. Carbon dioxide levels were also measured to determine indoor air quality, and questionnaires distributed to obtain the subjective comfort levels of occupants. Measured data is compared to the Passive Houses design criteria, the Austrian standards, and to the questionnaire responses.

It was found that both kindergartens experience warmer temperatures overall than the design parameters, and that the Passive House Kindergarten, (PHKG), has lower humidity levels in the winter months. The majority of questionnaire responses from the PHKG indicated that occupants still found the rooms to be cold in winter, but the Standard Kindergarten, (SKG), users found the rooms to be too warm. Measured indoor air quality (IAQ) in the PHKG was better in the winter months than in the SKG according to both the measured carbon dioxide levels and questionnaire responses. However, IAQ in both kindergartens improved significantly in the warmer months of April and May when the occupants began to open windows for longer daily durations showing similar indoor concentrations to outdoor carbon dioxide concentrations. Energy consumption for heating was lower for the PHKG; with slightly higher electricity consumption in the PHKG due to the additional electricity required for the ventilation system and solar panel circulation pumps. The temperature set points of both kindergartens should be adjusted and maintained in relation to the expectations of the occupants and it would be recommendable to adjust ventilation controls to carbon dioxide levels.

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1. Introduction

1.1. Purpose

The primary objective of this study is to determine if observable thermal comfort improvements are perceptible in the design criteria developments for Passive House kindergartens while reducing overall building energy consumption.

In order to determine if progress has been made, a comparison between two case study kindergartens was conducted using a kindergarten built to contemporary Austrian standards as a point of reference for comparison to the passive house kindergarten.

The heat demand calculations for a Passive House kindergarten are more stringent than the design requirements that were used in for kindergarten design in Austria in 2000. The objectives of this study are twofold: to assess if the kindergartens are able to provide a thermally comfortable environment and to ascertain if energy consumption may be minimized while providing a comfortable interior environment in kindergartens.

1.2. Motivation

The three major industries that consume energy are transport, industry, and buildings in descending order (International Energy Agency, 2009). Energy consumption of buildings depends significantly on the design and operation of indoor building controls to provide thermal comfort, primarily as temperature, ventilation, humidity, and lighting. Research has shown that the quality of the indoor environment affects the health, productivity, and comfort of the inhabitants, and shows a relationship between good indoor environmental quality, overall work, learning performance, and absenteeism. If occupants are uncomfortable, research has shown that they are likely to react to create a more comfortable environment whether or not it may have energy implications (ÖNORM EN 15251, p. 5).

Depending upon the source, it is estimated that peak or maximum oil production has either already been surpassed, or will be reached by approximately 2020. The cost of further oil extraction increases exponentially, raising the price of oil to a point where it will reach an unfeasible cost to extract oil further (Oil Depletion Analysis Centre & Post Carbon Institute, 2009). The turning point is when half the oil reserves have been extracted, and the relationship of production rate over time is displayed as a bell-curve as originally postulated by M. King Hubbert in his 1956 paper, “Nuclear Energy and the Fossil Fuels”.

According to the BP Statistical Review of World Energy 2007, peak oil production has already been reached in over 60 of the world's 98 oil producing countries. Research and development into alternative and sustainable power sources to fossil fuels is ongoing, however at this time, no single alternative energy source in production is able to provide energy economically, has the equivalent convertible energy potential per unit, nor is able to deliver the necessary quantity to meet current demands in comparison to fossil fuel sources (International Energy Agency, 2009). From the latest IEA statistics, renewable energy sources comprise only 0.7% of total global energy supply. Combined with hydroelectric power and combustible renewable energy sources and waste, 12.7% of total energy supply originates from non-fossil fuel sources aside from nuclear power (International Energy Agency, 2009). It is estimated that biodiesel from algae may be able to provide an alternative source to fossil fuels, including the flexibility to produce plastics and subsidiary materials from the algal source in massive quantities; however, the algal biodiesel is not yet commercially available due to the high cost of production and operation and maintenance costs. The estimated time to come to market is short, the best estimate in a report by Pike Research is that commercial production will commence in 2012 (Pike Research, 2009). Another report published by the US Department of Energy states that the cost of algae-based biofuel production is double the cost of petroleum oil refining (Sheehan, Dunahay, Benemann, & Roessler, 1998). The high costs are related to the high energy required to dry out the algae, and the low biomass content because of limited light penetration (Yanquin, Horsman, Wu, Lan, & Dubois-Calero, 2008). A transition to a renewable primary energy source is still in the future. Thus, the need to increase primary energy consumption efficiency, and reduce consumption of fossil fuels remains a topic of contention.

This study endeavours to ascertain if the comfort levels as outlined in the Austrian standards are satisfactory, or if users will react to modify their indoor environment to achieve a higher level of comfort by measuring the physical indoor conditions and determining the occupants' comfort levels by use of questionnaires.

1.3. Information Organization

The following thesis is broken down into six sections. Section 2 outlines the background of the project; Section 3 gives a general description of the kindergartens, the standards that each kindergarten was built to, and an overview of the aspects that will be investigated in this study. Section 4 gives the methodology and descriptions of the equipment used for collecting data. Section 5 gives the results of the study, discussing the findings that ensued from the investigation. Section 6 concludes the study.

2. Background

2.1. Development of the Passive House Standard

The methodology of designing a building to the Passive House standard began as collaboration between Dr. Bo Adamson and Dr. Feist. The first passive house was realized in Darmstadt Kranichstein in 1991. Since that time, there have been more than 6,000 examples of Passive Houses built (Passive-On Project, 2007), and the methodology is being adopted by the European Union as the next building performance benchmark across Europe commencing in 2011 (European Parliament, 2008). The Passive House methodology has been expanded from a design methodology for a single family home, to various building types, classified generally as residential and non-residential typologies. One non-residential typology, kindergartens, is the focus of this study.

The Passive House building standard is based on a checklist of performance and quality criteria for achieving low energy consumption and maintaining a high quality indoor environment. The primary requirements are listed below:

1. Annual heating requirement of 15 kWh·$(m^2a)^{-1}$ or less;
2. Combined primary energy consumption of 120 kWh·$(m^2a)^{-1}$ for heating, hot water, and electricity;
3. Total window (glazing and frame) U-values of 0.8 W·$(m^2K)^{-1}$ or less;
4. Southern orientation of large fenestration areas for maximum passive solar gain, and minimal fenestration on the north side;
5. Airtight construction with an air leakage rate of 0.6 h^{-1} or less;
6. High efficiency air-to-air heat recovery with a heat recovery rate of 80% or greater;
7. High efficiency energy saving appliances (Passivhaus Institut, 2009).

The uncontrolled air exchange that traditionally results from draughts and other building leakages no longer exist in a Passive House due to the airtight building envelope construction; a mechanical ventilation system is then required to ensure a constant fresh air supply. The ventilation rate is designed with a low air change rate without air recirculation to significantly reduce the ventilation energy requirement while maintaining a fresh air supply.

The Passive House standard was originally conceived with the goal of reducing the heating load in the cold season to 10 W/$(m^2$·a) or less, thereby eliminating the need for a standard heating system, and allowing the heated supply air from the compact ventilation system with heat recovery to provide the main source of room heating and a constant supply of fresh air

(Passivhaus Institut, 2009). The study period of this investigation takes place from December 2008 to May 2009 in order to observe the behaviour of the kindergartens in relation to energy consumption and comfort primarily during the cold months.

2.2. Current Comfort Requirements of Austrian Kindergartens

Human comfort is simply defined as “a state of mental and physical well-being” (Hens, 2007). To achieve this state, a person must attain three types of comfort: thermal, acoustic, and visual. This study will focus on thermal comfort.

2.2.1. Thermal Comfort

Thermal comfort is dependent upon the ability of a person to radiate heat to the environment (Hens, 2007). Several factors influence the rate of heat exchange by a person such as ambient temperature, surface temperatures, solar radiation, air speed, and relative indoor humidity. There are two subcategories of thermal comfort: global comfort and local comfort (Riccabona, 2008).

Global comfort is defined as the total body heat balance; whereas local comfort is comfort that is based on local conditions such as when cold winter drafts create stratification of interior air, e.g. warmer temperatures at higher levels and cooler temperatures at floor level. The determination of global and local comfort can be calculated following the parameters as outlined in ÖNORM EN ISO 7726 (Riccabona, 2008).

For an accurate assessment of thermal comfort, it is also important to take into account a person’s activity level measured in met and amount of clothing worn in units of Clo.

The recommended minimum acceptable Category 1 winter operative temperature for kindergartens is 19.0°C (ÖNORM EN 15251, 2007). The winter Category A operative temperature range for kindergartens as defined in ÖNORM EN ISO 7730 as 20.0°C ± 1.0°C. The importance of overheating due to solar irradiation is negligible in winter.

A maximum air speed of 0.10 $m \cdot s^{-1}$ is recommended by ÖNORM EN ISO 7730.

A relative indoor humidity of 30% to 65% and absolute air humidity between 4 and 12 $g \cdot kg^{-1}$ are accepted as comfortable ranges (Szokolay, 2004). Depending upon the level of activity, the perceived comfort level varies. It has been determined that a 10% increase in relative humidity is perceived as a temperature increase of 0.3°C. However, perceived temperature and humidity will be affected by clothing and activity levels (ÖNORM EN ISO 7730, 2006).

Calculations to determine standard effective temperature, SET, assume a relative humidity of 50% (Szokolay, 2004).

For the purposes of this study, it is assumed that activities are primarily sedentary. The activity level used in this study is 1.4 met (ÖNORM EN ISO 7730, 2006).

2.2.2. Indoor Air Quality

Indoor air quality may be classified using one of five methodologies as outlined in Austrian Standard, ÖNORM EN 13779:2007. For the purpose of this study, the indoor carbon dioxide levels will be used as a determinant for Indoor Air Quality, IAQ. IAQ is measured as a carbon dioxide concentration above outdoor air concentrations and classified according to the amount of carbon dioxide in the air. The concentrations are categorized on a scale from 1 to 4, with 1 as the best value based upon the concentration of indoor pollutants and particulate in the air. See Table 1 below for specific values.

Table 1: CO_2 levels as determinants for categorizing indoor air quality (ÖNORM EN 13779, 2007).

Indoor CO_2 Concentration in Rooms

Category	CO_2 Concentration above the Outdoor Air CO_2 Concentration in ppm	
	Normal Range	Standard Value
RAL 1	≤ 400	350
RAL 2	400 – 600	500
RAL 3	600 – 1 000	800
RAL 4	> 1 000	1 200

See Section 5.4 for the IAQ analysis.

As kindergartens are not unclean environments, the main source of indoor pollutants in the kindergartens is people, and it is possible to determine the ventilation rates of the kindergartens using CO_2 concentrations. Indoor carbon dioxide measurements are more accurate during the winter months as windows are usually left closed against the cold, lowering the fresh air supply to the rooms (ÖNORM EN 15251, 2007).

In accordance with ÖNORM EN 13779:2007, the exhaust air volume from classrooms must meet Exhaust Air Category 1 requirements, “exhaust air with a low pollution concentration”, while the volume of exhaust air from toilets and kitchens must meet Category 3, “exhaust air with a high pollution concentration”.

Supply air is classified as Category 1 in accordance with Table 7 of EN 13779:2007, as it contains only outdoor air with no air recirculation.

The maximum average air velocity for kindergartens is calculated differently for the winter (heating period), and summer (cooling period). It is divided into three classes: A, B, and C, with corresponding values of 0.10 $m \cdot s^{-1}$, 0.15 $m \cdot s^{-1}$, and 0.19 $m \cdot s^{-1}$, according to the level of thermal comfort that is desired (ÖNORM EN ISO 7730, 2006). ÖNORM B 8110-6 calculates the average monthly air change rate as seen in Formula (1).

$$\eta_{L,m,h} = (\eta_L \cdot t_{Nutz,d} \cdot d_{Nutz})/t \qquad (1)$$

$\eta_{L,m,h}$ average monthly air change rate for heating [h^{-1}]

η_L required hygienic air change rate [h^{-1}]

$t_{Nutz,d}$ daily period of use [$h \cdot d^{-1}$]

d_{Nutz} monthly period of use in days [$d \cdot M^{-1}$]

t total monthly period [$h \cdot M^{-1}$] (ÖNORM B 8110-6 , 2007)

The population density of classrooms is amongst the highest of the occupancy types. 2 to 5 m^2 per person is used as a design value (ÖNORM EN 13779, 2007).

2.2.3. Lighting

Lighting is a key factor of human comfort. Room illuminance levels for any specific point are affected by several parameters:

- Sky conditions
- Window orientation, size, type, and transparency
- Reflectance from wall and ceiling surfaces
- Room index
- Total effective flux
- Position relative to windows

Minimum window areas are defined by the Austrian regulations as a minimum of 10% of a room's overall floor area for room depths of five meters or less. For floor areas greater than five meters, the overall window area increases by 1% (Österreichisches Institut für Bautechnik, 2007). The recommended illuminance range in classrooms is 300-500 lx (ÖNORM EN 12665, 2009).

Glare is a problem in artificially lit interiors. According to Szokolay, people are more tolerant of glare in naturally lit spaces than artificially lit ones.

There are two glare types: disability and discomfort. In most cases, glare causes discomfort, but does not hinder vision to an extent that a person is blinded by glare. As the difference between the required indoor lighting levels and the exterior source varies so greatly, solar protection against glare is important for maintaining even lighting levels (Szokolay, 2004).

Measured lighting levels are outside the scope of this investigation. The effect of lighting on human comfort is addressed in the questionnaire responses.

2.2.4. Acoustics

Acoustics are divided into seven subcategories:

- Building acoustics
- Room acoustics
- Street noise
- Airborne sound between rooms within the kindergarten
- Impact noise
- Noise from mechanical systems

The first three categories involve refinement of the transmission of sound within an interior space to maximize audibility in the rooms, while sound originating from the last three categories is considered as sound disturbances and within acoustic design, the maximum noise reduction is desirable to attenuate noise levels to the lowest acceptable values.

The degree of sound absorption depends upon the occupancy of the room. Each person acts as a sound absorber, and reverberation times are greater for empty classrooms when compared to fully occupied rooms. A study performed by Sato and Bradley has shown that reverberation times for occupied classrooms have been decreased by approximately 10% when compared to empty classrooms (Sato & Bradley, 2008).

Measured acoustics levels are outside the scope of this investigation. The effect of acoustics on human comfort is addressed in the questionnaire responses.

2.2.5. Energy Efficiency

With the introduction of the Energy Performance of Buildings Directive in 2002, the member states of the European Union committed to reduce the annual energy demands and publish the total annual energy consumption of each newly constructed and renovated building as an energy certificate (European Parliament and the Council of the European Union, 2002). This meant that the above listed comfort criteria such as air change rate, indoor ambient temperature, relative humidity, and lighting levels must be provided while utilizing less overall energy.

Various Austrian standards have been, and continue to be developed to address calculation methodologies for each specific aspect, and the Austrian Institute for Building Technology

(Österreichischen Institut für Bautechnik) Directive 6 focuses upon the relationship of energy conservation to thermal insulation requirements (Österreichisches Institut für Bautechnik, 2007). The methodology is based upon maximizing the thermal performance of the building envelope, minimizing losses, and maximizing passive and active solar gains. Because the building envelope is airtight, i.e. minimized losses by air infiltration and exfiltration, internal gains from people, equipment, and lighting may be included as heat sources further reducing the overall heat load. The calculations also account for thermal heat storage in the building envelope according to construction type classified as massive, mixed, and light construction. The end effect is that the mechanical systems should theoretically be reduced up to a factor of 10 for the lowest energy building types, including Passive Houses. The regulation of the HVAC systems are automatically controlled by thermostats and a constant air change rate is assured using mechanical ventilation with heat recovery and a low air flow rate for a consistent indoor climate. Austrian building regulations continue to become more stringent over time.

The calculation of the thermal resistance of the external envelope is covered in ÖNORM B 8110-1 giving design U-Values for the roof, exterior walls, floor slab, and exterior doors and windows for calculating total building energy efficiency as seen in Table 2.

Table 2: U-Values for the roof, exterior walls, floor slab, and exterior doors and windows for calculating total building energy efficiency (ÖNORM B 8110-1, 2007).

Exterior walls facing exterior air:	0.4 W·(m2·K)$^{-1}$
Slab on grade & basement walls:	0.4 W·(m^2·K)$^{-1}$
Windows and transparent building parts to exterior air, glazed and unglazed exterior doors:	1.7 W·(m^2·K)$^{-1}$
Exterior rooflights:	1.7 W·(m^2·K)$^{-1}$
Roofs and ventilated or uninsulated attics:	0.2 W·(m^2·K)$^{-1}$

ÖNORM 8110-2 deals with condensation; Part 3 focuses upon solar heat gains and thermal storage; Part 5 contains climate models and user profiles including kindergartens.

ÖNORM B 8110-6 contains detailed calculations for defining the annual heat demand, annual cooling demand, air change rate, ventilation rate, total heat losses, and total heat gains, including passive solar heat gains through glazing.

2.3. Austrian Kindergarten Building Requirements in the Year 2000

The Standard Kindergarten has been built to the requirements of the Viennese Building Code. The following sections will list the relevant requirements as contained in the regulations and the reference U-Values for building assemblies.

2.3.1. Thermal Comfort

§106 states that rooms generally are to be heated.

2.3.2. Carbon Dioxide Levels in Indoor Air

§105 generally outlines that people are not to be exposed to dangerous emissions. There is no ventilation system in the standard kindergarten. Thus the carbon dioxide levels for indoor air in general will be taken into account.

2.3.3. Indoor Air Exchange Rate

§106 states that rooms must have access to ventilation, especially natural ventilation, and that heating systems must be properly exhausted. Similarly, as no ventilation system has been installed, the air change rate shall be calculated according to Formula (2):

$$q_{vZUL}=q_{m,E}\cdot(c_{RAL}-c_{ZUL})^{-1} \qquad (2)$$

$q_{v,ZUL}$ supply air volume rate [$m^3 \cdot s^{-1}$]

$q_{m,E}$ emission mass flow rate into the room [$mg \cdot s^{-1}$]

c_{RAL} allowable room concentration [$mg \cdot m^{-3}$]

c_{ZUL} concentration in the supply air [$mg \cdot m^{-3}$]

Due to the primary reliance of heat distribution over a forced air ventilation system, the question arises if low indoor air humidity in winter will occur as stale air is removed. One of the goals of a passive house is to maintain a comfortable environment including controlling interior temperature, humidity, air movement, and levels of indoor pollutants such as carbon dioxide.

2.3.4. Thermal Conductance of Exterior Building Elements

The acceptable values for exterior building elements in buildings built after 1993 are provided by the Viennese Building Code (Wiener Bauordnung und dazugehörige Verordnungen). Austrian Institute of Building Technology Directive 6: Guideline of Energy Characteristics of Buildings. The characteristic values for buildings fulfilling the Building Code are collected in Directive 6: The Guideline of Energy Characteristics of Buildings from the Austrian Institute of Building Technology. The values for structures built circa 2000 are outlined in Table 3.

Table 3: Reference U-values for buildings constructed after 1993 (Österreichisches Institut für Bautechnik, 2007).

Exterior walls	0.5 W·(m^{2}K)$^{-1}$
Basement floor slabs	0.4 W·(m^{2}K)$^{-1}$
Windows	1.9 W·(m^{2}K)$^{-1}$
Exterior doors	1.9 W·(m^{2}K)$^{-1}$
Roofs	0.2 W·(m^{2}K)$^{-1}$

3. Kindergarten Descriptions

The kindergartens share similarities in architectural programme, gross floor area, population, and heating systems. The following sections will compare relevant building and functional information for each kindergarten.

3.1. Passive House Kindergarten Building

3.1.1. Location

The Passive House Kindergarten (PHKG) is located on the edge of a quiet suburb called Breitenlee on the outer edge of the city. As visible in bottom-right corner of Figure 1, the kindergarten is on the periphery of the city; farmland neighbours the site.

Figure 1: Aerial photo of the passive house kindergarten outlined in orange (Google, 2009).

The kindergarten shares a property with an elementary school and a gymnasium which open onto a common inner courtyard. Figure 2 shows the shared property outlined in red. The kindergarten is shown in dark green (1), the elementary school is above the kindergarten (2), and the gymnasium is to the right of the kindergarten (3).

Figure 2: Passive house kindergarten site plan.[1]

Legend
1. Passive House Kindergarten
2. Elementary School
3. Gymnasium (sports hall)

The kindergarten building is a single-storey rectangular structure with a central east-west axis. Each classroom unit has an adjacent toilet, and all six south facing classrooms share common cloakroom spaces between classroom pairs. The south facing classrooms have floor-to-ceiling windows,

Figure 3. There are seven classrooms in total, one oriented to the west. On the north and east sides are two kitchens, offices for the kindergarten principal and secretary, staff room, mechanical room, and adult toilets. A generous central open atrium with skylights connects the classrooms to the support spaces, and is used for lunch and multipurpose activities.

Figure 3: South facade of the Passive House Kindergarten.

The building was designed by the Austrian architect Georg Reinberg and constructed in 2006. The building plan is visible in Figure 13.

[1] Site plan courtesy of Architect Reinberg.

3.1.2. Passive House Kindergarten Rooms

Figure 4 shows the interior of a typical kindergarten classroom with south facing floor to ceiling windows. Four of the five observed classrooms have a similar layout to Figure 4. After School Group 1 has smaller windows and faces west.

Figure 4: Typical classroom in the Passive House Kindergarten.

The rooms where measurements took place in the PHKG are listed in Table 4.

Table 4: Passive House Kindergarten room areas and volumes (Reinberg G. W., 2005).

Room	Area [m^2]	Volume [m^3]
Kindergarten 1	19.8	65.9
Kindergarten 2	60.2	198.7
After School Group 1	59.4	196.0
After School Group 2	79.3	261.8
Toddler's Group	59.7	197.0
Atrium	168.9	557.4
Kitchen	17.9	44.8
Children's WC	10.7	26.8
Staff Room	20.3	50.8
Corridor	35.3	88.3

3.2. Standard Kindergarten Building

3.2.1. Standard Kindergarten Location

The Standard Kindergarten (SKG), built in 2000, is located in a suburb closer to the city centre, on the Donauinsel (Danube Island), within the campus of an international organization. The kindergarten is outlined in orange in Figure 5.

Figure 5: Standard kindergarten location plan. (Google, 2009).

As visible in the top third of Figure 5, the kindergarten is adjacent to a forested area in the southern part of Donaupark; the main building of the international organization is below.

The standard kindergarten is a single storey structure with partial basement. The floor plan is an atypical form that reflects the floor plan of the international organization. The primary circulation area is circular, and the three pairs of kindergarten groups form 3 rectangular "hammerheads" in a circular array off the central corridor ring. See Figure 14 for the building plan.

3.2.2. Standard Kindergarten Rooms

The interior of a typical Standard Kindergarten classroom is shown in Figure 6.

Figure 6: Interior of a Standard Kindergarten classroom.

Similar to the passive house kindergarten, there are seven classroom groups organized into units. The classroom units have more variance in the floor plans: access into four of the classroom areas, Group Rooms 2, 3, 4, and 5, is through a common entranceway, with a shared cloakroom per classroom pair. These groups typically have classrooms (Figure 6) with an upper balcony (Figure 7), an individual toilet per group accessed from the common foyer, and a storage room off the main classroom.

Figure 7: Quiet area of typical Standard Kindergarten classroom.

Three of the classrooms have separate foyers/cloakrooms, and access to the adjacent toilet is from both main classroom area and the foyer. Group Rooms 6 and 7 have storage rooms adjacent to the main classroom, while Group Room 1 does not have a storage area. The basement floor has a multifunctional room, the mechanical and electrical rooms, storage space, and another toilet. The observed rooms in the SKG are listed in Table 5.

Table 5: Standard Kindergarten room areas and volumes (Hayek, 2000).

Room	Area [m^2]	Volume [m^3]
Group Room 1	56.0	219.3
Group Room 2	60.0	233.3
Group Room 3	60.0	233.3
Group Room 4	60.0	233.3
Group Room 7	56.0	219.3
Atrium	96.9	339.3
Kitchen	20.2	50.5
Children's WC	10.2	25.5
Staff Room	19.8	49.4
Multipurpose Room	61.7	216.1

3.3. Building Constructions

As part of the design process, the Passive House Kindergarten's building performance was calculated to minimize heat loss through the external envelope, reducing the overall heat demand, and allowing a smaller heating system to be installed than the contemporary Austrian standard.

The thermal resistance of both external envelopes are broken down into roof, external wall, floor slab, and door & window U-values.

3.3.1. Roof Constructions

The SKG has a U-Value that is double that of the PHKG. Table 6 lists the roof U-Values for both kindergartens. As most of the heat is lost through the roof, the amount of roof insulation in this area should be reflected by less heat loss through the PHKG roof in both the simulation and measured results. No sound insulation value is available for the PHKG.

Table 6: Roof U-Values for both kindergartens (Reinberg G. W., 2005), (Hayek, 2000).

	Building Element	U-Value [W·(m^2·K)$^{-1}$]
PHKG	Roof	0.10
SKG	Roof	0.20

3.3.2. Exterior Wall Construction

The exterior wall U-Value of the PHKG is approximately one-third that of the SKG, which reflects better thermal resistance and a slower rate of heat loss than the SKG. Table 7 outlines the exterior wall U-Values for both kindergartens.

Table 7: Exterior Wall U-Values for both kindergartens (Reinberg G. W., 2005), (Hayek, 2000).

	Building Element	U-Value [W·(m^2·K)$^{-1}$]
PHKG	Exterior Wall	0.13
SKG	Exterior Wall	0.38

3.3.3. Floor Slab

The PHKG has slab-on-grade construction while the SKG has two floor slab constructions with slab-on-grade for most of the building, with a basement under a portion of the north section. The thermal conductivity values are higher in the SKG than the PHKG. Table 8 shows the floor slab

U-Values for both kindergartens. As the soil has a partially insulating effect and due to the buoyancy effect, it is expected that the difference in thermal conductivity between the kindergartens will have a smaller impact on overall rate of heat loss.

Table 8: Floor Slab U-Values for both kindergartens (Reinberg G. W., 2005), (Hayek, 2000).

	Building Element	U-Value [$W \cdot (m^2 \cdot K)^{-1}$]
PHKG	Floor Slab	0.18
SKG	Slab on Grade	0.38
	Basement Floor Slab	0.38

3.3.4. Windows & Doors

All exterior windows in the PHKG are triple-glazed with composite insulated frames, an exterior aluminum shell, and have an overall U-Value of 0.85 W/m^2K. The glazed south façade has exterior blinds. Roof lights have a U-Value of 0.9 W/m^2K with exterior automatically controlled shading, and exterior doors have a U-Value of 1.0 W/m^2K. All exterior windows have a sound insulation value of 43 dB. Exterior doors have a sound insulation value of 38 dB.

In the SKG, all windows are double-glazed units with window frame U-Values of 1.6 W/m^2K and glass U-Values of 1.1 W/m^2K. Windows have a minimum sound insulation value of 38 dB. The roof lights over the atrium are triple glazed with insulated glass and have an overall U-Value of 0.9 W/m^2K and sound insulation of 43 dB (Hayek, 2000). Table 9 summarizes the window and door U-Values for the kindergartens.

Table 9: Window and door U-Values for both kindergartens (Reinberg G. W., 2005), (Hayek, 2000).

Building Element	PHKG U-Value [$W \cdot (m^2 \cdot K)^{-1}$]	SKG U-Value [$W \cdot (m^2 \cdot K)^{-1}$]
Window	0.85	1.60
South Glazed Façade	0.90	-
Door	1.00	1.60
Roof Light	0.90	0.90
Solar Collector	0.80	-

3.4. Other Values for Calculating Annual Heat Demand

The architect originally calculated the thermal comfort values for the PHKG according to ÖNORM B 8110. A summary of the annual heat demand and thermal gains and losses are contained in Table 10.

Table 10: Heat gains and losses in the PHKG (Reinberg, Energiesparkonzept Schukowitzgasse, 2005).

Specific annual heat demand calculated following the standard (ÖNORM B 8110-6 , 2007)	17.8 kWh·(m²·a)⁻¹
Total Annual Heating Demand	17.9 kWh·a⁻¹
Transmission Heat Losses	53.6 kWh·(m²a)⁻¹
Ventilation Heat Losses	8.8 kWh·(m²a)⁻¹
Internal Heat Gains	16.3 kWh·(m²a)⁻¹
Solar Heat Gains (without Solar Collectors)	32.1 kWh·(m²a)⁻¹
Usable Heat Gains	92.0 %

3.5. Gross Floor Area

The PHKG is slightly bigger (17%) than the SKG with a gross floor area of 1,298.0 m^2. Comparative areas and volumes are listed in Table 11.

Table 11: Comparison of gross floor areas of both kindergartens (Reinberg G. W. Energiesparkonzept Schukowitzgasse, 2005), (Hayek, 2000).

	Gross Floor Area [m^2]	Gross Volume [m^3]
PHKG	1,298.0	4,932.4
SKG	1,080.0	3,219.2

3.6. Heating Systems & Domestic Hot Water

3.6.1. Passive House Kindergarten Heating, Ventilation, & Domestic Hot Water

There are two types of heating systems using water and air working together. The primary system is the combined underfloor and in-wall heating system (murocaust and hypocaust system) that is coupled with the solar panels located on the south facade. Figure 8 shows a schematic of the heating system. In total, there are 83 m^2 of solar collectors.

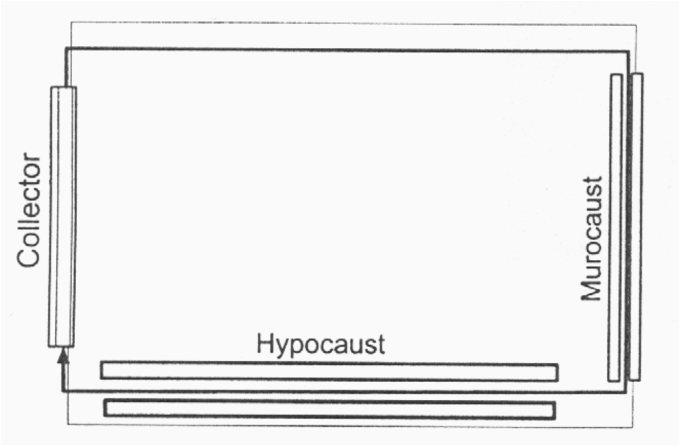


Figure 8: Schematic of the secondary heating system from the solar collectors.[2]

The solar panels provide hot water for both heating and DHW. The designed wall surface temperature is 22-24°C and floor temperature is 18-22°C to create an overall ambient air temperature of 21°C during occupancy. The surface area of the solar collectors is relatively large to ensure that both heating and hot water may be provided during the winter season. Half of the designed winter heat gain is as direct solar irradiation into the rooms, and the other half as heat transferred into the hypocaust and murocaust system. The combined passive heat gains are designed to carry half the winter heat demand (Reinberg, Energiesparkonzept Schukowitzgasse, 2005). Figure 9 shows the collectors on the south facade as a black band above the classroom windows.

Figure 9: South facade of the passive house kindergarten.[3]

A secondary mechanical ventilation system with high efficiency heat recovery is coupled with a compact gas air heater. The incoming fresh air passes through an earth tube, an underground

[2] Diagram courtesy of Architect Reinberg.
[3] Photo courtesy of Architect Reinberg.

pipe that preheats the air by adopting the constant ground temperature. This system is designed to provide fresh air and secondary heating. The calculated air supply is 30 L per person·h, and is designed to maintain carbon dioxide levels below 1,000 ppm for a population of 165 people (Reinberg G. W., Energiesparkonzept Schukowitzgasse, 2005). The heater warms the supply air after it is preheated by the high efficiency air-to-air heat exchanger. This is the standard type of heating system in a passive house. There are no radiators. Residual heating is provided by a gas boiler (Reinberg, Reinberg: Ecological Architecture - Design - Planning - Realization, 2008).
A 3,800 litre DHW storage tank is connected to the solar panels as seen in Figure 10. The DHW demand in kindergartens is higher than residential use. The storage tank is centrally placed in the kindergarten atrium, as a teaching tool for the children. Additional energy is saved by connecting the solar-heated hot water for dishwashing and laundry. Cold water is normally run to these appliances where an internal electric heater is used to heat the water (Reinberg, Reinberg: Ecological Architecture - Design - Planning - Realization, 2008).

Figure 10: Domestic hot water tank in the atrium of the PHKG.

3.6.2. Standard Kindergarten Heating System & Domestic Hot Water

The heating source is district heating from the City of Vienna. The secondary and tertiary heating circuits are separated using a 70kW plate heat exchanger. Underfloor heating is distributed throughout the kindergarten through nine manifolds. There are no radiators.

Domestic hot water is also from district heating, distributed via a plate heat exchanger with a power output of 40kW. Further domestic hot water is supplied with a 600 litre boiler to three distribution stations with circulation pumps.

3.7. Passive House Kindergarten Green Roof

The flat roof is covered by 1,032 m^2 of extensive green roof. In essence, a green roof is a secondary roof system that is built over the flat roof. The thermal mass of the soil and vegetation has a cooling effect, delaying the penetration of solar heat gain to the interior, and also contributes to reducing the overall carbon footprint of the kindergarten as the plants absorb carbon dioxide.

3.8. Population

3.8.1. Passive House Kindergarten Population

The kindergarten staff is comprised of 17 kindergarten teachers and 8 assistants, for a total of 25 staff members. There are 210 children divided into 7 groups with four group types:

1. Toddler's Group, 0 -3 years
2. Kindergarten Group, 3-6 years
3. Family Group, 3-10 years
4. After School Group, 6-11 years

3.8.2. Standard Kindergarten Population

The kindergarten staff is comprised of 15 kindergarten teachers, 10 assistants, and the kindergarten principal for a total of 26 staff members. There are 139 children with 52 boys and 87 girls ranging in age from three months to six years old. The children are divided into 7 groups with three group types:

1. Toddler's Group, 0 -3 years
2. Kindergarten Group, 3-6 years
3. Family Group, 3-10 years

3.9. Kindergarten Hours of Operation

The PHKG is in operation five days a week, closed on weekends, statutory holidays, and Christmas and Easter breaks. Children in the Toddler's Group are in the kindergarten mornings from 6:00

a.m. until noon, the Kindergarten and Family Groups are in the kindergarten for the whole day, and the After School Group is active in the afternoons from 1:30 p.m. until 6:00 p.m. The PHKG is open 12 hours/day each work day from 6:00 a.m. to 6:00 p.m. At the time that this investigation commenced, the PHKG has been in operation for a year and a half.

The SKG is in operation 10.5 hours a day during the work week from 7:00 a.m. to 5:30 p.m. It is closed on weekends and international holidays.

4. Methodology

Two kindergartens were studied, one built to the Passive House Standard, the other to Austrian Building Regulations of the year 2000. Field data was collected in two parts. The first part involved measuring the indoor temperature, relative humidity, and carbon dioxide levels using carbon dioxide monitors, and temperature and humidity data loggers. In each kindergarten, 10 data loggers and one carbon dioxide monitor were placed in various rooms. See Section 4.5.1 and 4.5.2 for specific logger locations. In total, 20 data loggers and two carbon dioxide monitors were used for this experiment. This equipment was used to ascertain the physical comfort levels and indoor air quality within each kindergarten.

The second part experimental method involved assessing the perceived comfort levels by the inhabitants of each kindergarten by using questionnaires. See Section 4.8.1 for a description of how the questionnaires were used.

A Predicted Mean Vote/Percentage of Persons Dissatisfied analysis was used to ascertain if comfort criteria were met as described in Section 4.6.2.

4.1. Study Period

Calculations for the thermal performance of buildings in Austria are primarily for the cold season, as it has a humid continental climate according to the Köppen classification (Peel, Finlayson, & McMahon, 2007). The winter measurement period was selected to study the effects during the heating season. The loggers were placed in the kindergartens on different dates according to when access was granted to the buildings.

4.1.1. Passive House Kindergarten Study Period

The data loggers were placed in the Passive House Kindergarten for the duration of 24 weeks, commencing from December 11th, 2008 to May 15th, 2009. Each data logger recorded the temperature and humidity in each study area at ten minute intervals. The carbon dioxide sensor, connected via cable to the data loggers, also measured indoor carbon dioxide levels every ten minutes.

4.1.2. Standard Kindergarten Study Period

Similarly, 10 data loggers, and one logger connected via cable to a carbon dioxide monitor, were placed in the Standard Kindergarten. Measurements were taken at ten minute intervals and the study period was 25 weeks, commencing from December 16th, 2008 to May 26th, 2009.

4.2. Exterior Weather Data

Local climate data as hourly values of exterior temperature and humidity were obtained from the Austrian Central Institute for Meteorology and Geodynamics (Zentral Anstalt für Meteorologie und Geodynamik) for the period of December 1st, 2008 to May 31st, 2009. The climate data was taken from the Hohe Warte Weather Station, the closest weather station to both kindergartens.

4.3. Equipment Used

Temperature and humidity data loggers and carbon dioxide monitors were used for the investigation.

4.3.1. Onset HOBO U12-012 Data Logger

The HOBO U12 data logger has internal sensors to assess temperature, relative humidity, and lighting levels. The carbon dioxide sensors data output was recorded by the HOBO via a 4 V-20 mA cable. The manufacturer's specifications state that the operational temperature range is -20°C to 70°C, with an accuracy of ±0.35°C from 0°C to 50°C. The recording humidity range is 5% to 95% with an accuracy of ±2.5% from 10% to 90% relative humidity. Readings are able to be made at various time intervals; the sampling rate used for the experiment was 10 minutes. Each logger unit has a storage capacity of 64 KB and is battery operated. The lithium ion battery life is approximately one year. Data is downloaded from each individual logger using a USB cable connected directly into a computer using Greenline software (Onset Computer Corporation, 2009). The data logger unit is visible in Figure 11.

Figure 11: Onset HOBO U12-012 data logger (Arney, Pantagraph, 2008).

For the purposes of this experiment, the temperature and relative humidity readouts were used.

4.3.2. Carbon Dioxide Monitors

A Telaire 7001 monitor was originally placed in the Passive House Kindergarten on December 11th, 2008. As the carbon dioxide monitor was battery operated, it was replaced one month later, on January 19th, 2009, with the Vaisala Carbocap GMW22 carbon dioxide monitor operated from mains electricity. One carbon dioxide monitor was installed per kindergarten, and was connected to the HOBO data loggers which recorded the carbon dioxide readings at 10 minute intervals. The carbon dioxide monitors are seen in Figure 12.

Figure 12: Telaire 7001 and Vaisala Carbocap GMW22 carbon dioxide monitors (Arney, Pantagraph, 2008; Vaisala, 2009).

4.3.3. Telaire 7001

The Telaire 7001 monitor is able to measure carbon dioxide and temperature using a dual beam absorption infrared sensor. It has a 4 Volt output, by which the carbon dioxide readings were logged in the HOBO loggers. The Telaire monitors are able to detect carbon dioxide levels from 0 to

10,000 ppm, and record levels, when connected to the HOBO loggers, from 0 to 2,500 ppm with an accuracy of 50 ppm or 5%, whichever is greater. The monitor is able to operate between 0°C to 50°C and a relative humidity of 0% to 95%. It is battery operated, with a battery life of 80 hours (Telaire, 2008).

4.3.4. Vaisala Carbocap GMW22

The Vaisala Carbocap sensor uses a single beam, dual wavelength, NDIR silicon-based sensor. The range of carbon dioxide readings are from 0 to 2,000 ppm with an accuracy of ±2%. Operating conditions are from -5°C and to 45°C and humidity range from 0% to 85%. It has a 4 Volt output that was connected into the HOBO data logger (Vaisala, 2009).

4.4. Data Logger Locations

The data loggers and carbon dioxide monitor were placed in the Passive House Kindergarten as seen in Figure 13, and the Standard Kindergarten as per Figures 14, and 15. The carbon dioxide monitor is attached to Data Logger 1 in each kindergarten.

4.5. Physical Measurements

The results of the logged temperature and relative humidity are discussed in the Sections 5.1 to 5.3.

4.5.1. Passive House Kindergarten Logger Locations

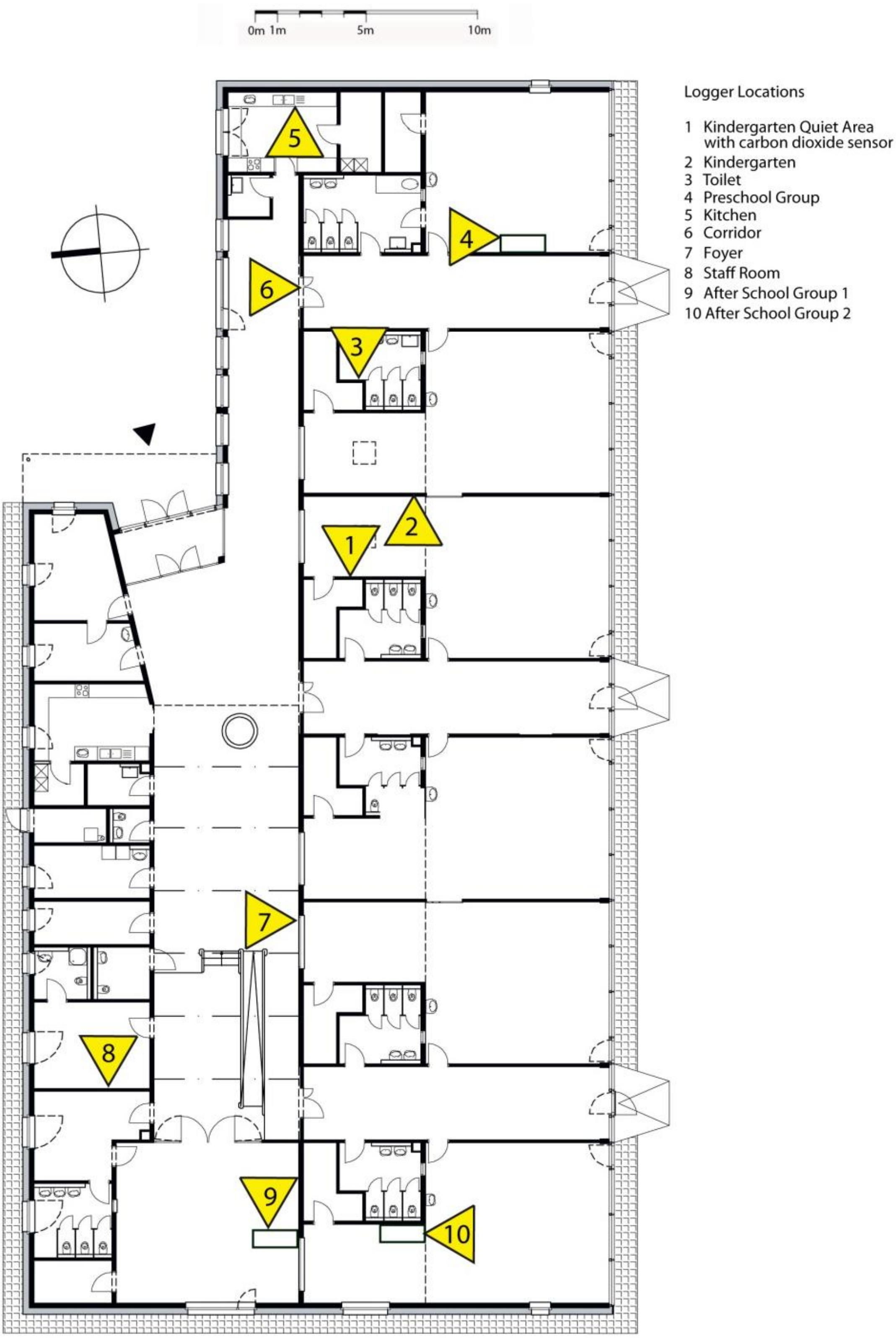


Figure 13: Plan of the Passive House Kindergarten showing data logger locations. Logger 1 also measures carbon dioxide.

4.5.2. Standard Kindergarten Logger Locations

Figure14: Plan of the Ground Level of the Standard Kindergarten showing data logger locations. Logger 1 also measures carbon dioxide.

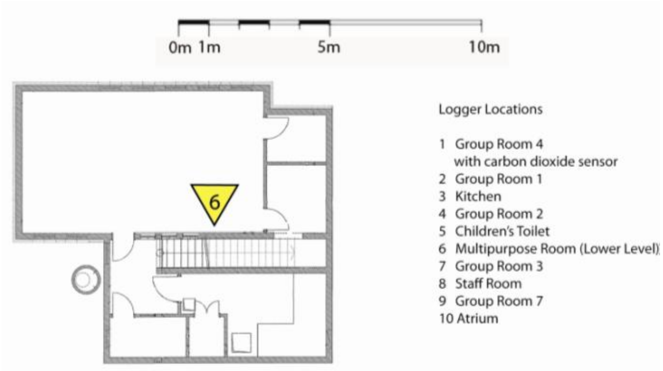


Figure15: Plan of the Lower Level of the Standard Kindergarten showing data logger location.

4.6. Thermal Analysis

The data from the loggers was analysed using Excel. Data is broken down into two parts: thermal analysis and indoor air quality. The thermal analysis was studied in various intervals: period of study, months, weeks, and hourly values.

Two scenarios were used: fully occupied and unoccupied kindergartens. The schedule of occupancy was determined by the holiday schedule and operational hours of each kindergarten.

Measured values were compared to user perceptions in the questionnaires.

4.6.1. Thermal Comfort

Psychrometric charts were used to show the relationship of temperature to relative humidity. A comfort zone, the range of acceptable comfort conditions, was constructed using Formulae (3) and (4) to determine the upper and lower limits at 50% relative humidity:

$$\Theta_{i\,max} = 0.33\ \Theta_{rm} + 18.8 + 2 \qquad (3)$$

$$\Theta_{i\,min} = 0.33\ \Theta_{rm} + 18.8 - 2 \qquad (4)$$

$\Theta_{i,\,max}$ maximum limit value of the indoor operative temperature [°C]

$\Theta_{i,\,min}$ minimum limit value of the indoor operative temperature [°C]

Θ_{rm} external running mean temperature [°C] (ÖNORM EN 15251, 2007)

The set point temperatures for the kindergartens were established according to Category I in the same standard. The correlation between calculated comfort and measured temperature and relative humidity readings was shown when the data, plotted as temperature vs. relative humidity, which fell within the calculated comfort zone.

4.6.2. Predicted Mean Vote & Percentage of Persons Dissatisfied

The predicted mean vote, PMV, is an estimation of perceived thermal comfort calculated on a scale from -3 (very cold) to +3, very hot using the measured temperature and relative humidity values, occupants' clothing values, activity level, and air velocity according to ÖNORM EN ISO 7730. The assumed clothing values are 1.0 Clo for winter, 0.85 Clo for spring, and 0.5 Clo for summer. The activity level of the inhabitants was taken at 1.4 met, and the air velocity was assumed at 0.1 $m \cdot s^{-1}$. The recorded temperature and relative humidity data sets during occupancy hours have been used to generate the PMV values.

The predicted percentage of dissatisfied, PPD, is calculated from the PMV values.

4.7. Energy Analysis

A copy of heating and electricity bills from the PHKG was collected from October 1st, 2007 to September 30th, 2008, and from the SKG from January 2nd, 2008 to January 2nd, 2009. The common period during January 2nd, 2008 to September 30th, 2008 will be used for the energy analysis.

The primary goal of all buildings built to the passive house standard is to reduce the annual heating energy demand to 15 $kWh/m^2 \cdot a$ while maintaining good indoor thermal comfort conditions.

The annual heating demand is calculated using the monthly heating demand with Formula (5),

$$Q_h = (Q_T + Q_V) - \eta \cdot (Q_S + Q_I) \qquad (5)$$

Q_h	monthly heating energy demand [kWh]
Q_T	monthly transmission losses [kWh]
Q_V	monthly ventilation losses [kWh]
η	utilization factor [-]
Q_S	monthly solar gains [kWh]
Q_I	monthly internal gains [kWh]

The results of Formula (5) are then used in Formula (6) to determine the annual heating demand per unit area,

$$HWB_{GFA} = \sum Q_h / GFA \qquad (6)$$

HWB_{GFA}	annual heating demand [$kWh/m^2 \cdot a$]

GFA gross floor area [m^2] (Riccabona, 2008)

The annual heating demands have been calculated and compared for both buildings according to ÖNORMs B 8110 and H 5056 using the data from the energy bills, indoor temperatures measured from the data loggers, average exterior temperature from a local weather station, as well as building drawings and specifications.

The heating energy requirement combines the total energy required for space heating and DHW, and is calculated according to the Formula (7).

$$Q_{HEB} = Q_l - \eta_h \cdot (Q_g + Q_{recovery}) + Q_H + Q_{tw} + Q_{TW} + Q_{HE} \qquad (7)$$

Q_{HEB} heating energy demand [kWh]

Q_l transmission and ventilation heat losses [kWh]

η_h utilization factor for determining the usable portion of gains that can be used for the annual heating demand [-]

Q_g heat gains from solar, lighting, equipment and people [kWh]

$Q_{recovery}$ recoverable portion of equipment losses [kWh]

Q_H heating equipment losses [kWh]

Q_{tw} DHW heat demand [kWh]

Q_{TW} DHW equipment losses [kWh]

Q_{HE} auxillary energy [kWh]

The energy analyses are calculated using the Excel tool from *Baukonstruktionslehre 4* by Riccabona, and are compared to the energy bills in Section 5.7.

4.8. User Perceptions

A questionnaire of 28 questions was drafted in German, and distributed to the staff of each kindergarten via a third party at each kindergarten to ascertain perceived comfort. The participating kindergarten teachers and assistants answered the questionnaires individually.

4.8.1. Questionnaires

The questionnaire is divided into four categories: general user data, comfort, habits, and health. See Section 8.2.1 for the blank questionnaire and Section 5.6 for questionnaire results.

Both kindergarten principals were informed that a study into comfort was being conducted, and informed staff and children of the study.

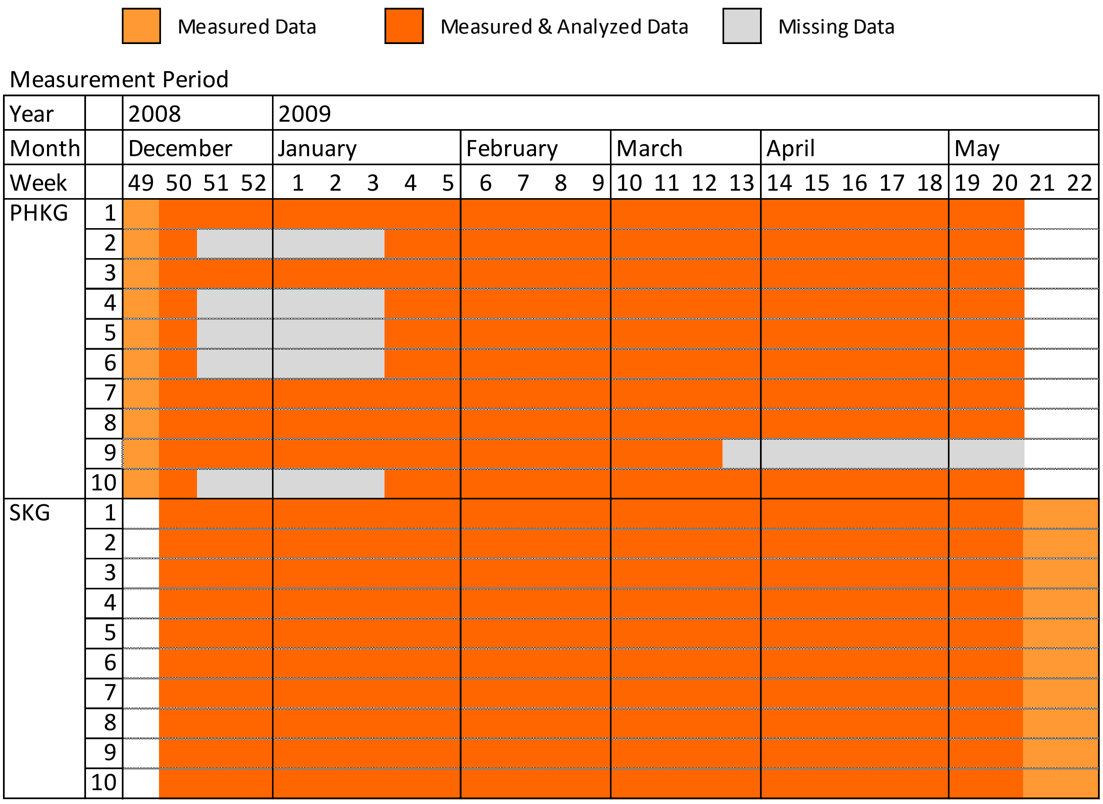
5. Results and Discussion

5.1. Measurements

The measurement period was slightly different for each kindergarten. Data from only the common period was compared for the purpose of this study, and is shown in dark orange in Table 12. The lighter orange areas indicate the remaining measurement period where data was collected, but not analyzed. The gray areas show where data sets for Data Loggers 2, 4, 5, 6, and 10 from the PHKG are incomplete from December 18th, 2008 to January 19th, 2009 and for Data Logger 9 from March 27th until May 15th, 2009. The batteries in the loggers went flat before the data could be downloaded.

The data set for the SKG is complete for all data loggers as seen in Table 12.

Table 12: Kindergarten measurement period.



5.2. Data Logger Results

In each kindergarten, five classrooms were monitored for a total of 10 studied areas. The summary results of the study period are illustrated below in a series of histograms for temperature, and relative humidity and carbon dioxide levels for the occupied portion of the comparative study period commencing from December 11th to May 15th, 2009.

Five pairs of secondary rooms are compared in each kindergarten: Staff Rooms, Atria, Kitchens, Children's Toilets, and PHKG Corridor to SKG Multipurpose Room.

5.2.1. Temperatures – Classrooms

The temperature ranges of the five classrooms in each kindergarten are combined as one result per kindergarten in the graphs below. The overall temperature range with upper and lower temperature limits as outlined in the Standard are shown in the unmasked (white) portions of Figure 16.

Figure 16 illustrates the frequency of temperatures occurring in the 10 classrooms for the six-month period. Temperatures most often remain between 23°C and 26°C for over 70% of the entire observation period.

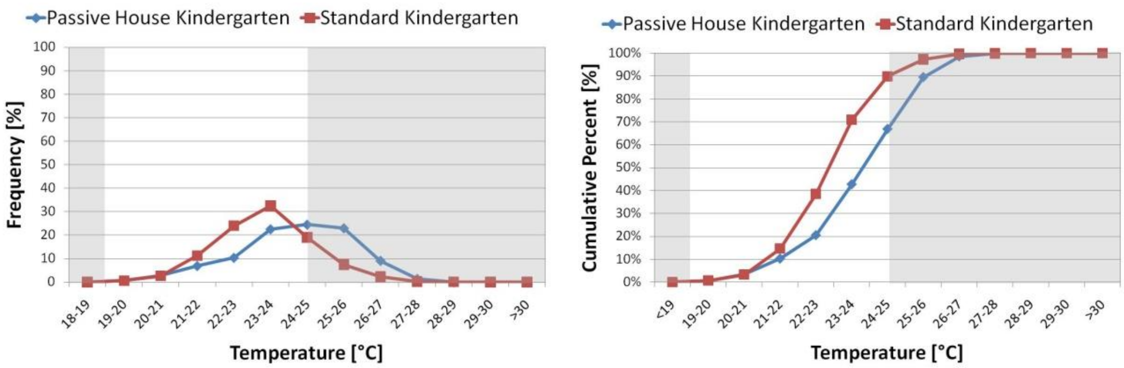


Figure16: Temperatures in the occupied classrooms for the observation period: temperature bins (left), cumulative temperature distribution (right).

The Standard Kindergarten (SKG) has a tendency to remain between 22°C and 25°C for over 75% of the study period, showing a cooler 1K temperature preference than the PHKG. There is a larger overall temperature distribution of 11K, from 18°C to 29°C.

5.2.2. Temperature – Secondary Rooms

The temperatures in the secondary rooms for the observation period are presented in Figures 17 to 21. The rooms are compared singularly for each kindergarten.

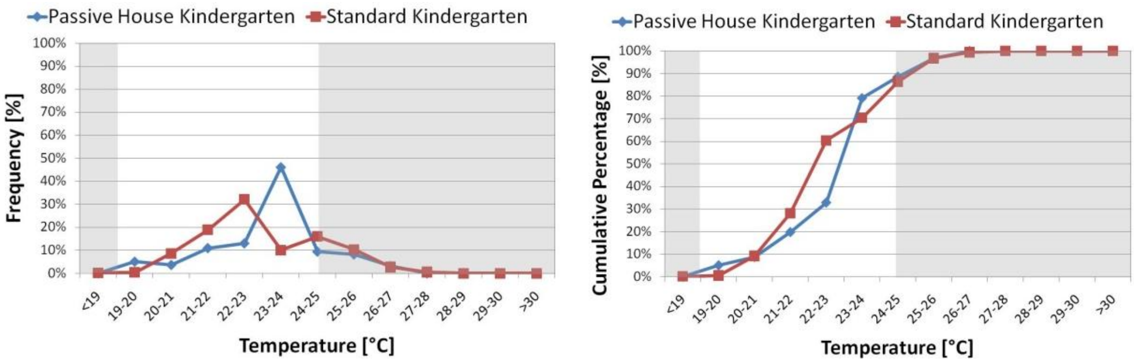


Figure17: Temperatures in the Staff Rooms during the occupied portion of the observation period: temperature bins (left), cumulative temperature distribution (right).

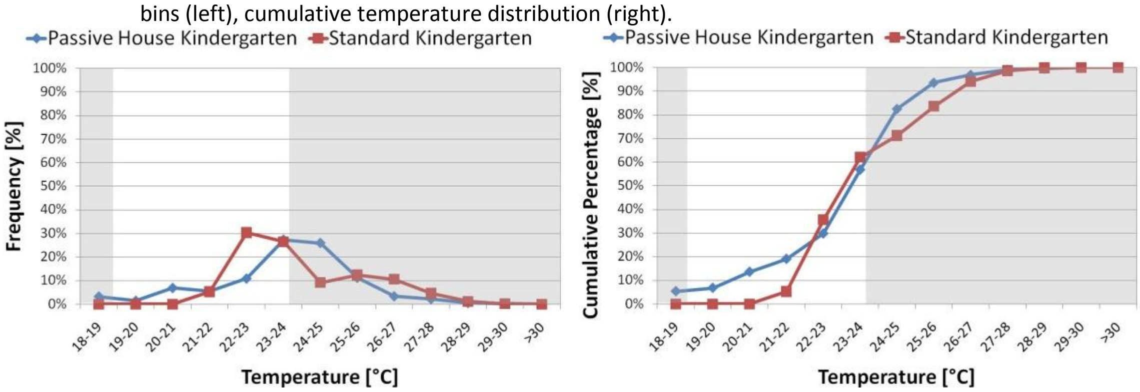


Figure18: Temperatures in the Atria during the occupied portion of the observation period: temperature bins (left), cumulative temperature distribution (right).

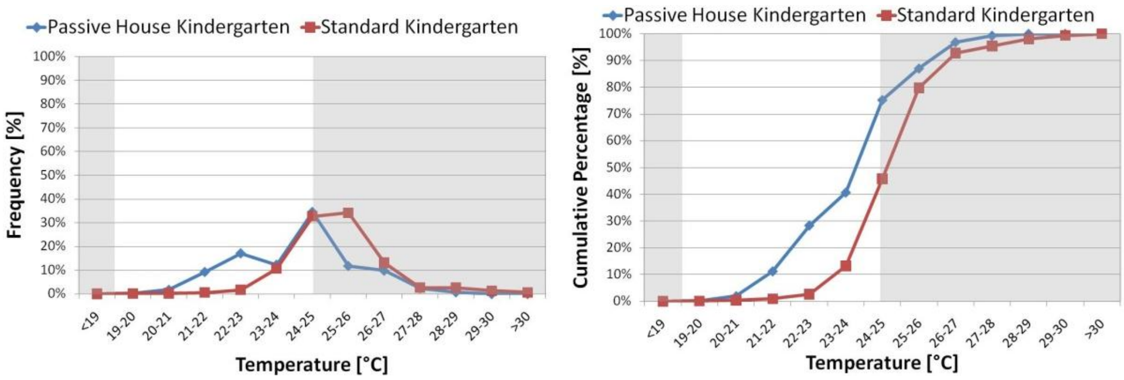


Figure 19: Temperatures in the Kitchens during the occupied portion of the observation period: temperature bins (left), cumulative temperature distribution (right).

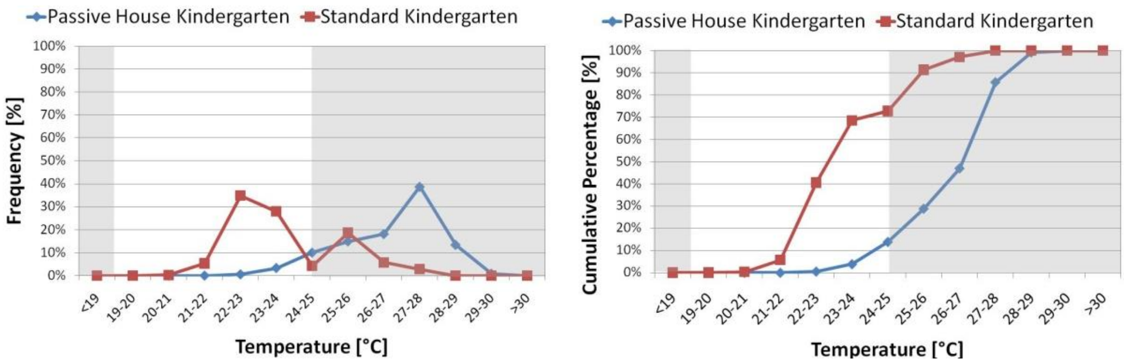


Figure 20: Temperatures in the Children's Toilets during the occupied portion of the observation period: temperature bins (left), cumulative temperature distribution (right).

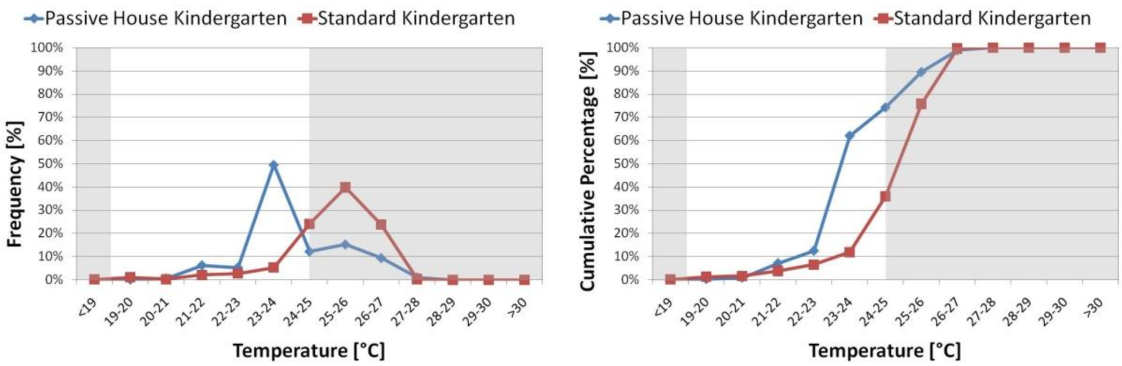


Figure 21: Temperatures in the Corridor and Multipurpose Room during the occupied portion of the observation period: temperature bins (left), cumulative temperature distribution (right).

The temperature values observed in the secondary rooms of both kindergartens are often close to or above the upper temperature limit. A large portion of the temperatures in the PHKG Children's Toilet are extremely warm, often at 27°C (Figure 20). Temperatures in the Kitchens are also warm assumed to be due to cooking and baking activities (Figure 19). However, temperature values in the Kitchens are lower than that which is in the PHKG Children's Toilet. It is odd that the temperature of the PHKG toilet is so high, as it is a room with relatively low occupancy, no window to the exterior, and is thermally coupled to the adjacent classrooms whose dominant temperature values are cooler, at 25°C (Figure 20).

The Multipurpose Room in the SKG also has very warm values, with temperatures often at 26°C (Figure 21). The high temperature in this room is also odd, as the room has no windows to the exterior for solar irradiation, and the intuitive assumption is that the room would be cooler due to its location in the basement of the building, following the physical principle of thermal stratification.

5.2.3. Monthly Temperature Results – Classrooms

The upper and lower temperature limits are different for the cold and warm seasons as discussed previously. The specified acceptable temperature ranges in the standard, 19°C to 21°C for winter, and 22.5°C to 24.5°C in summer, are shown in Figures 22 to 27 in the unmasked sections.

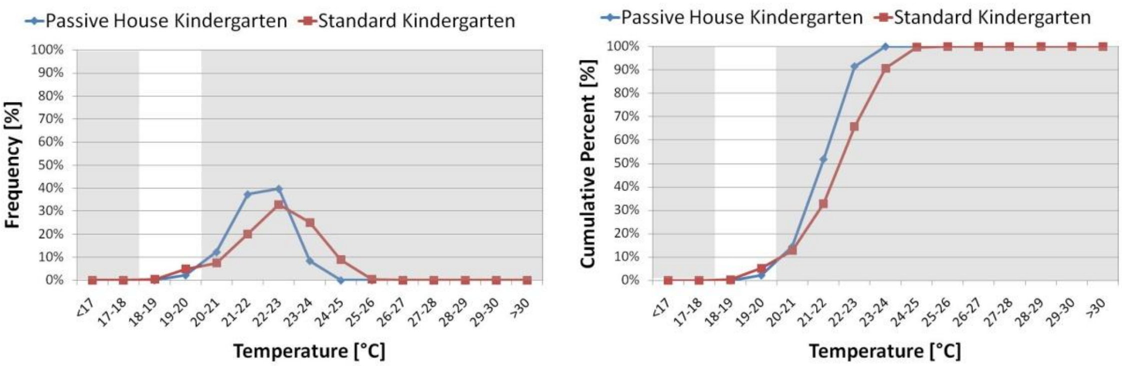


Figure22: Classroom temperatures in December: temperature bins (left), cumulative temperature distribution (right).

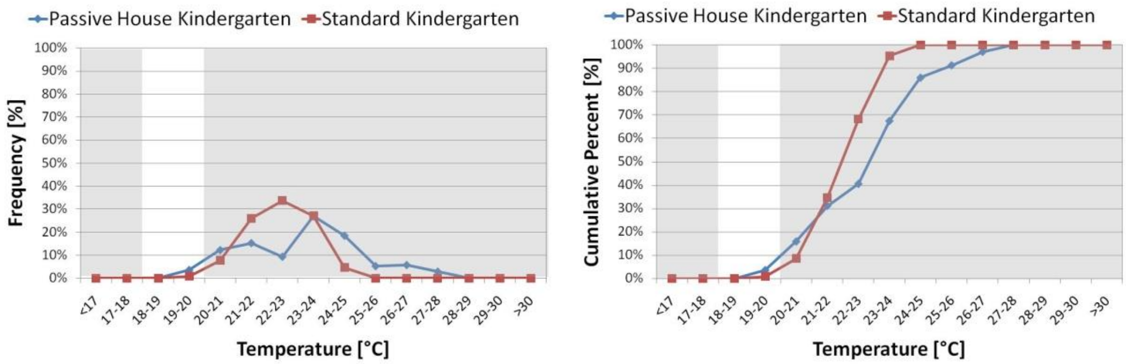


Figure 23: Classroom temperatures in January: temperature bins (left), cumulative temperature distribution (right).

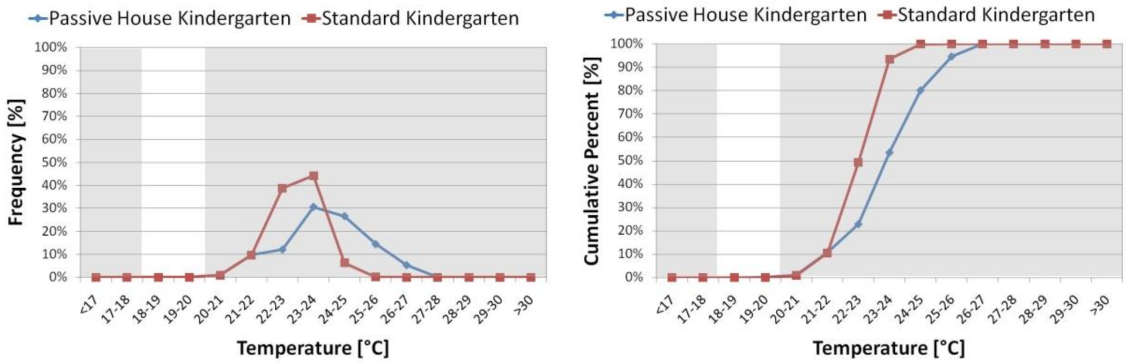


Figure 24: Classroom temperatures in February: temperature bins (left), cumulative temperature distribution (right).

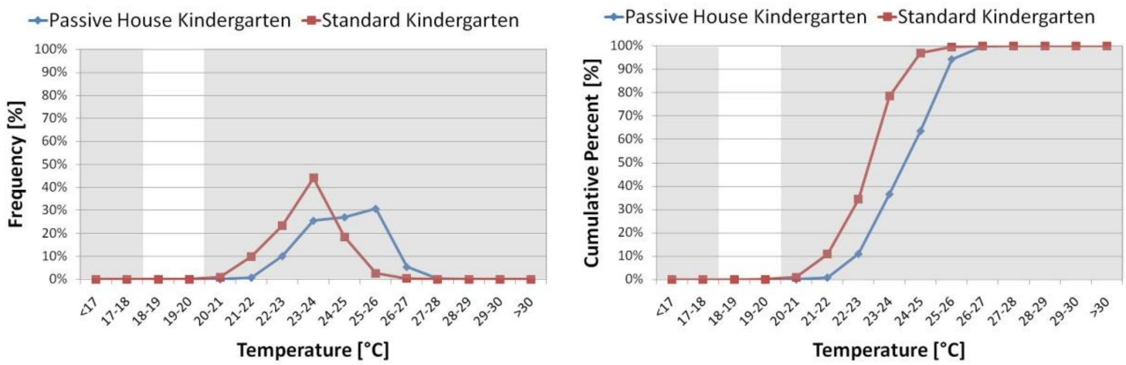


Figure 25: Classroom temperatures in March: temperature bins (left), cumulative temperature distribution (right).

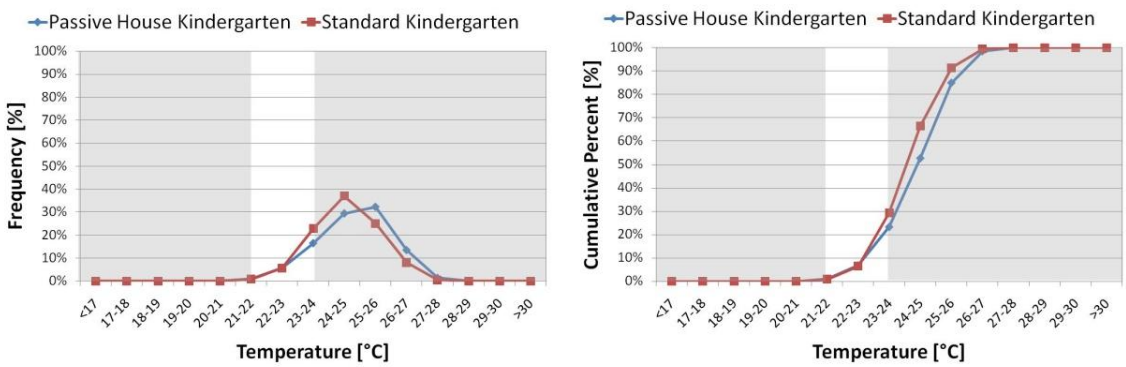


Figure 26: Classroom temperatures in April: temperature bins (left), cumulative temperature distribution (right).

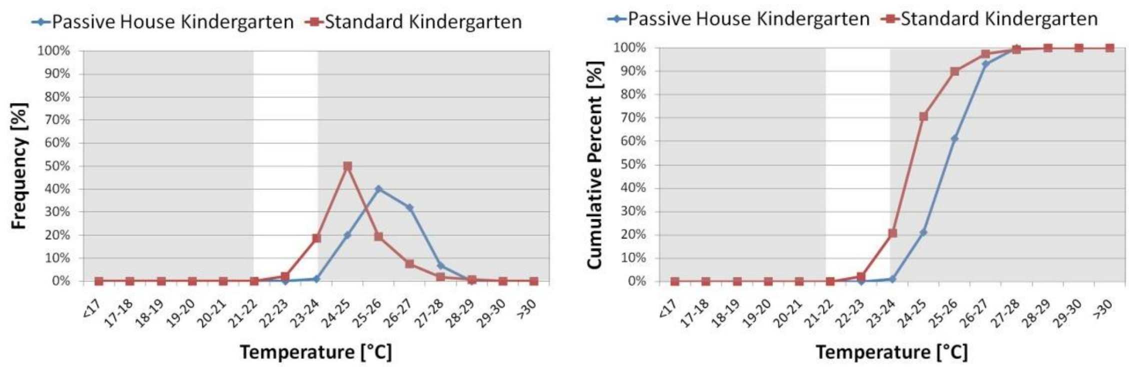


Figure 27: Classroom temperatures in May: temperature bins (left), cumulative temperature distribution (right).

As seen in the monthly temperature values, the classrooms have constantly warmer temperatures than the standard for each month. The PHKG classrooms have warmer values for all months. All dominant temperature values are significantly higher than the defined upper limits in both the cold and warm seasons in the standard. All recorded temperature values in both kindergartens for February and March are higher than the upper limit.

Overall, the temperature distributions of both kindergartens are very similar, mainly differing only by 1K. Both kindergartens are relatively warm in winter when compared to the set point values as outlined in ÖNORM EN ISO 7730 which has lower and upper limits of 19°C and 21°C respectively for the cold season. According to the standard, the assumed clothing values measured in Clo units are 0.5 Clo for the summer season, and 1.0 Clo for the winter season. The PHKG has a tendency to be 4K warmer, and the SKG, 3K warmer. The measured temperatures show less variation from the standard's upper and lower limits for the warm season, which are 22.5°C to 24.5°C. The SKG remains within the limits; however, the PHKG is still 1K warmer than the upper limit of the summer design values.

In Figure 16, the warmer tendency is clearly shown in blue by the PHKG by the right shift of temperature values. The steeper slope of the SKG values indicates a greater change between temperature values. The values within the cold and warm season comfort boundaries in accordance with ÖNORM EN ISO 7730 are shown in unmasked portions of the graphs.

The monthly temperature graphs of the classrooms which follow in Section 5.2.3 illustrate the monthly temperature changes.

See the results of the monthly psychrometric charts in Section 5.3 for the percentage of time that the average classroom temperature ranges meet the comfort criteria.

5.2.4. Relative Humidity – Classrooms

The comfortable humidity range is determined to be between 30% and 70% as outlined in the European Standard (ÖNORM EN 13779, 2007). According to the definition in the standard, the SKG is within comfortable humidity limits. However, the generally accepted indoor humidity range is between 40% and 60% (Sterling, Arundel, & Sterling, Criteria for Human Exposure to Humidity in Occupied Buildings, 1985). Following this definition of a comfortable humidity range, the PHKG is below the lower comfortable humidity limit for more than 35% of the time, whereas the SKG is below the lower humidity limit only 8% of the time.

The lower humidity limit as defined by the standard is shown in dark gray. The lighter gray portion shows the lower humidity limit as defined by Sterling, Arundel, & Sterling.

Figure 28 illustrates the frequency of indoor humidities occurring in the 10 classrooms for the observation period. PHKG humidities are between 30% and 70% for over 79% of the entire observation period. SKG humidity levels remain from 30% and 70% for 92% of the time.

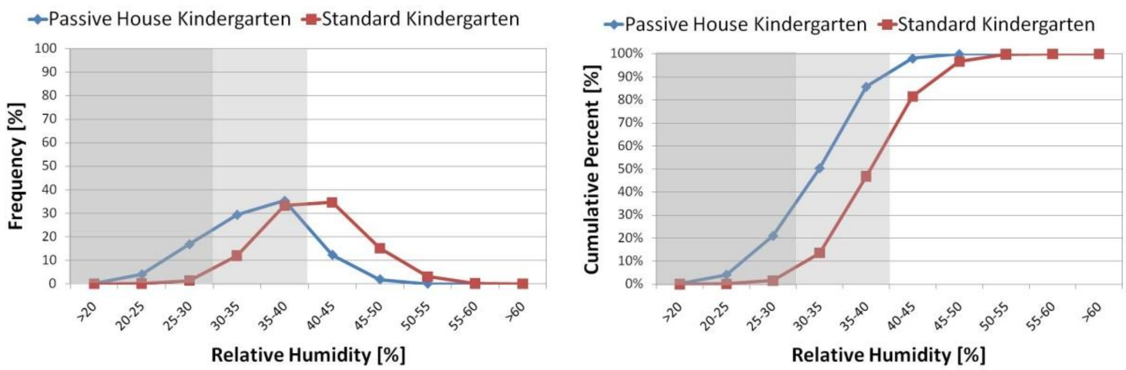


Figure 28: Indoor humidities in the occupied classrooms for the observation period: humidity bins (left), cumulative humidity distribution (right).

The relative humidity range of the PHKG is drier than the SKG, with the peak humidity 5% lower than in the SKG (Figure 28). The drier interior may partially be due to the warmer temperature, loss of moisture from the exhaust air, or lower occupancy to building volume ratio. The graph of the cumulative humidity distribution also shows a drier tendency in the PHKG. The monthly analyses in Section 5.2.6 show the humidity patterns in greater detail.

5.2.5. Relative Humidity – Secondary Rooms

Humidity values are often between 30% and 40% for the secondary rooms (Figures 29 to 33) with the exception of the Kitchens (Figure 31), where humidity values are slightly higher at 40% and 45% for the SKG and the PHKG respectively. It is assumed that the indoor humidity level in the Kitchens is affected by moisture production from cooking, baking, and washing activities. Lower humidity levels in the PHKG Children's Toilet correspond to the warmer temperatures observed (Figure 32).

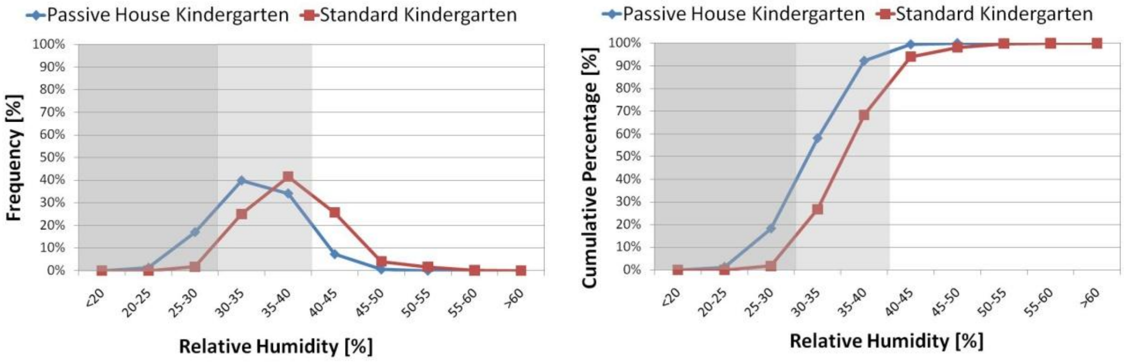


Figure 29: Indoor humidities in the Staff Rooms during the occupied portion of the observation period: humidity bins (left), cumulative humidity distribution (right).

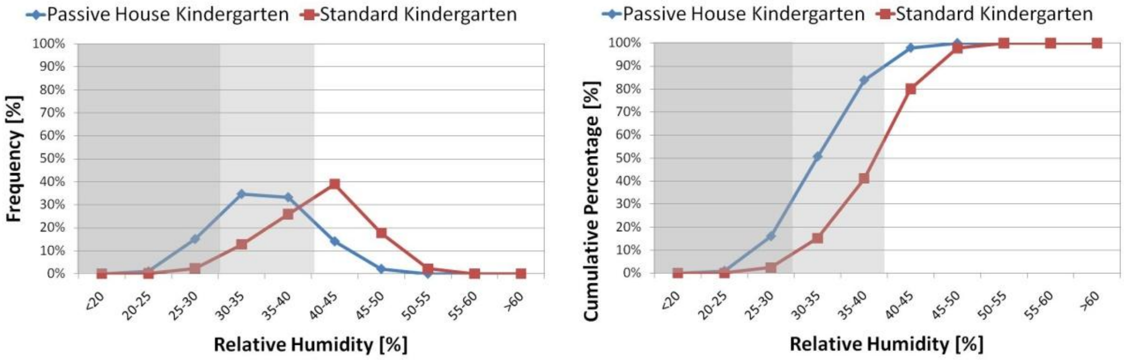


Figure 30: Indoor humidities in the Atria during the occupied portion of the observation period: humidity bins (left), cumulative humidity distribution (right).

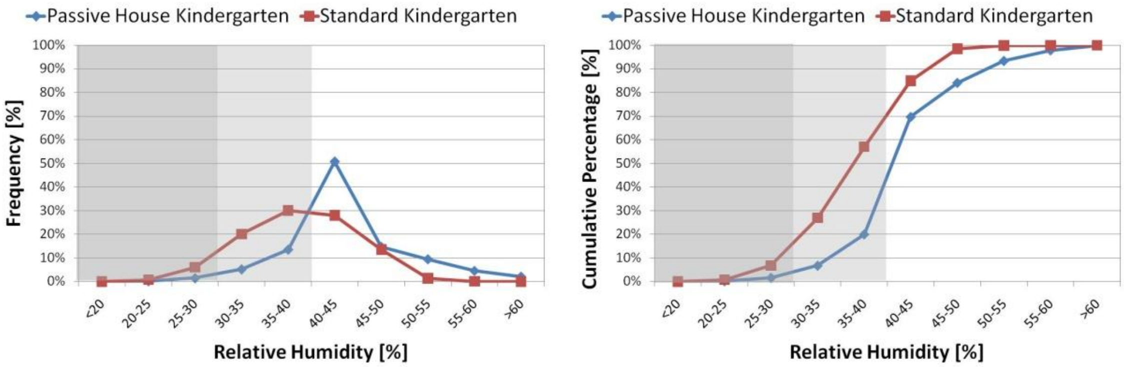


Figure 31: Indoor humidities in the Kitchens during the occupied portion of the observation period: humidity bins (left), cumulative humidity distribution (right).

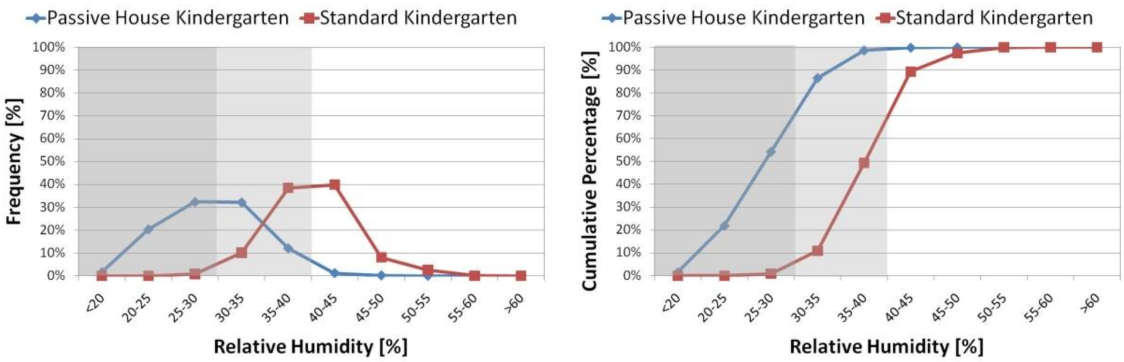


Figure 32: Indoor humidities in the Children's Toilets during the occupied portion of the observation period: humidity bins (left), cumulative humidity distribution (right).

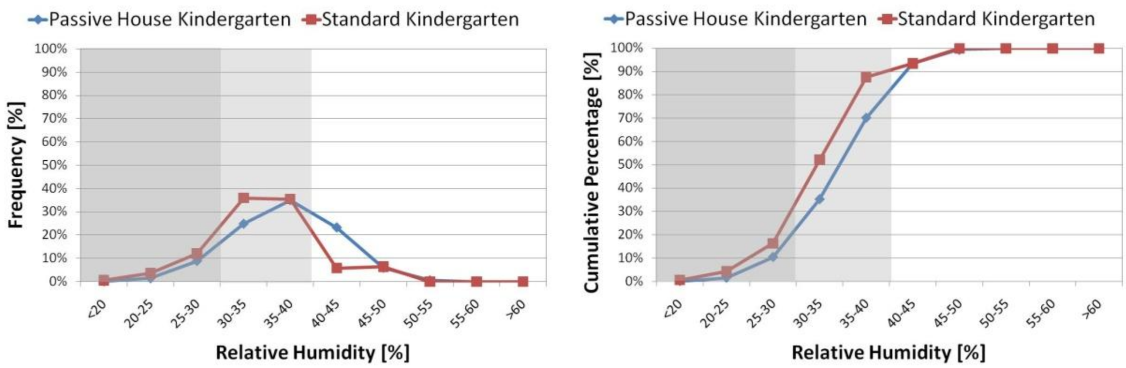


Figure 33: Indoor humidities in the Corridor and Multipurpose Room during the occupied portion of the observation period: humidity bins (left), cumulative humidity distribution (right).

5.2.6. Monthly Relative Humidity Results – Classrooms

The December humidity distributions are almost identical in both kindergartens, showing more concurrence between humidity values than temperature values (Figure 34). In January and February, the PHKG has values which are predominantly 10% drier, and temperature values are 1K warmer than the SKG (Figures 35 & 36). March values show a 5% humidity difference, with warmer temperature values also in the PHKG (Figure 37). In the warmer months of April and May, humidity distributions again become more similar, and a large portion of the May values begin to have higher humidities, perhaps reflecting the practice of opening windows for longer periods of time, i.e. three or more hours (Figures 38 & 39). Section 5.6.2 discusses users' responses to questions of thermal comfort.

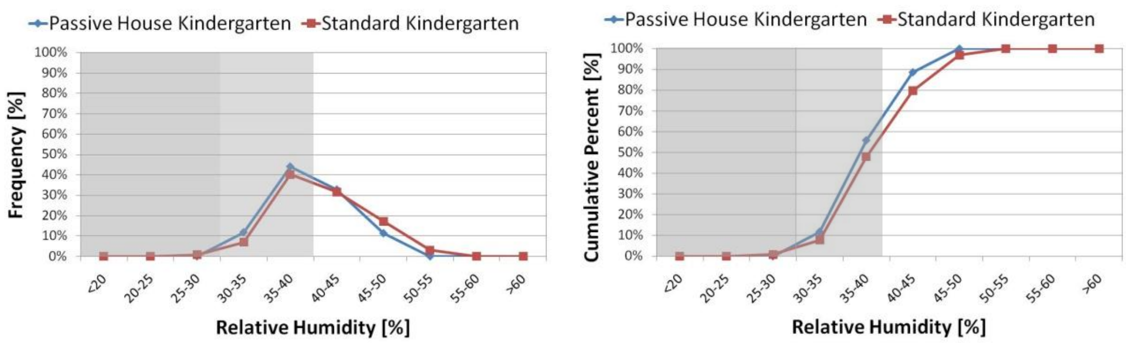


Figure 34: Classroom indoor humidities in December: humidity bins (left), cumulative humidity distribution (right).

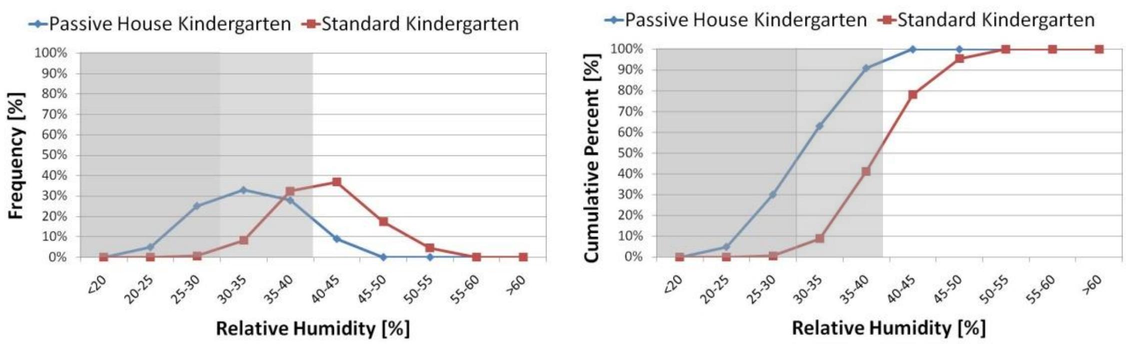


Figure 35: Classroom indoor humidities in January: humidity bins (left), cumulative humidity distribution (right).

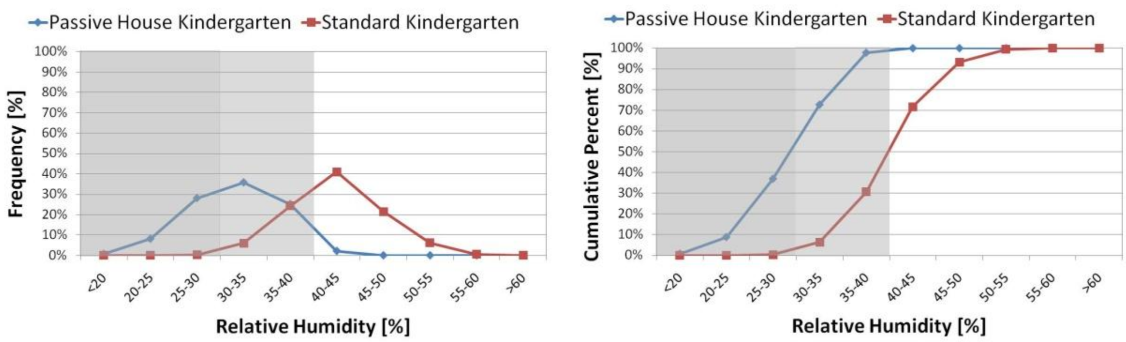


Figure 36: Classroom indoor humidities in February: humidity bins (left), cumulative humidity distribution (right).

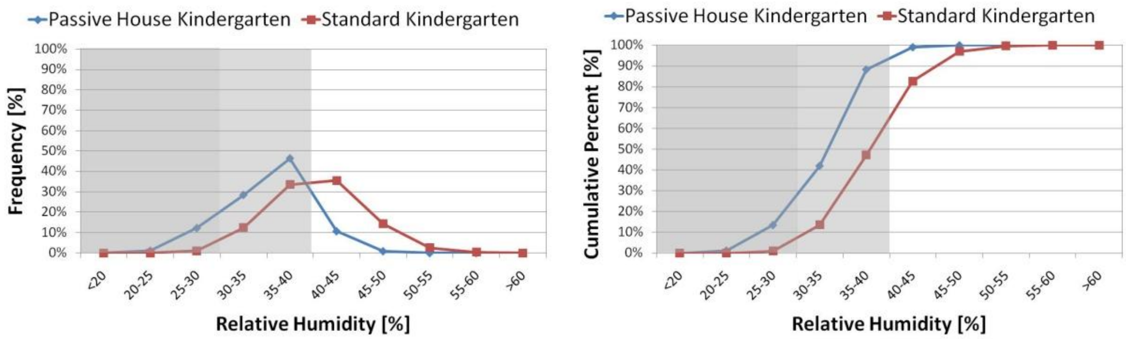


Figure 37: Classroom indoor humidities in March: humidity bins (left), cumulative humidity distribution (right).

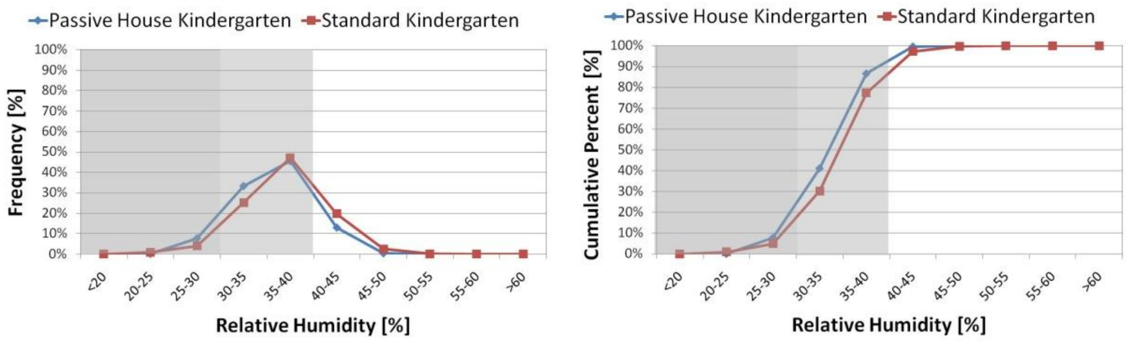


Figure 38: Classroom indoor humidities in April: humidity bins (left), cumulative humidity distribution (right).

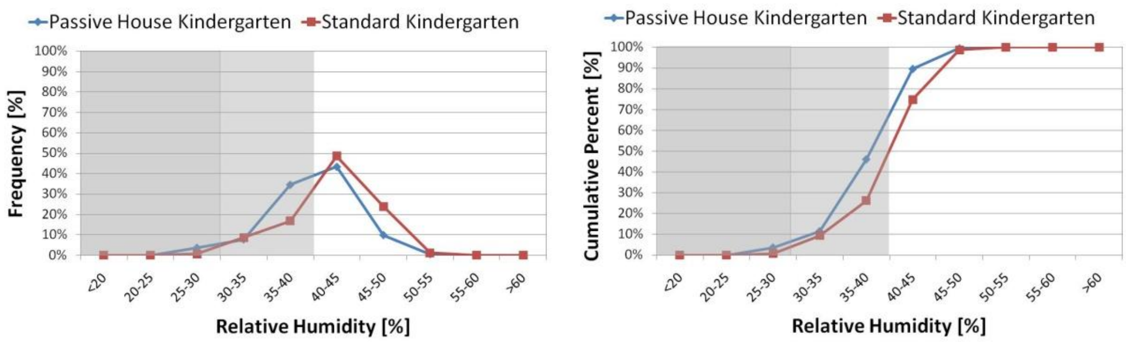


Figure 39: Classroom indoor humidities in May: overall humidity range and cumulative humidity distribution.

5.3. Psychrometric Analysis - Classrooms

The combination of temperature and relative humidity, in relation to the winter and summer set point temperatures and acceptable humidity ranges, are illustrated in the monthly classroom psychrometric analyses in Figures 40 to 45. The hourly temperature and relative humidity values for all classrooms in each kindergarten are grouped together with PHKG data points in red, and SKG data points in purple. The comfort criteria as established by ÖNORM EN ISO 7730 for temperature and ÖNORM EN 13779 for relative humidity form the boundaries of the quantified thermal comfort boundaries outlined in green as seen in Figures 40 to 45.

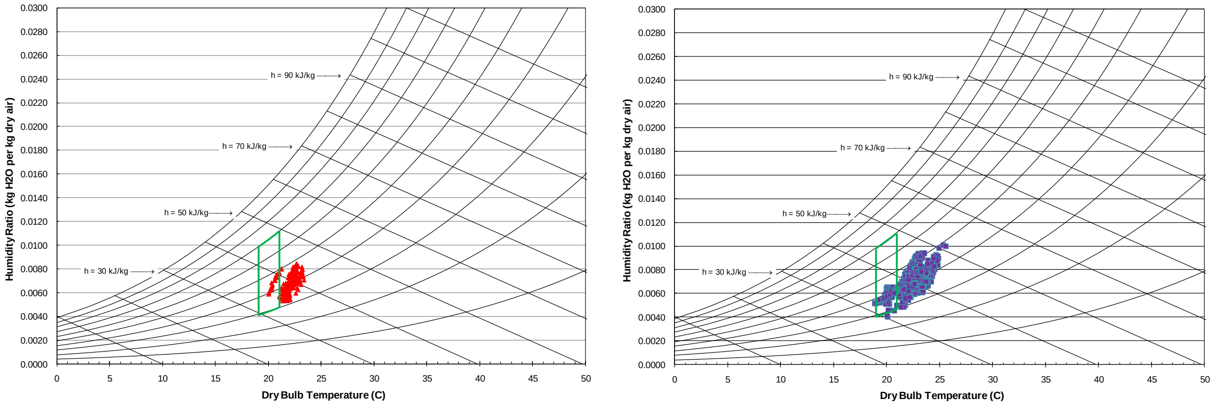


Figure 40: December classroom temperature & relative humidities: PHKG (left), SKG (right).

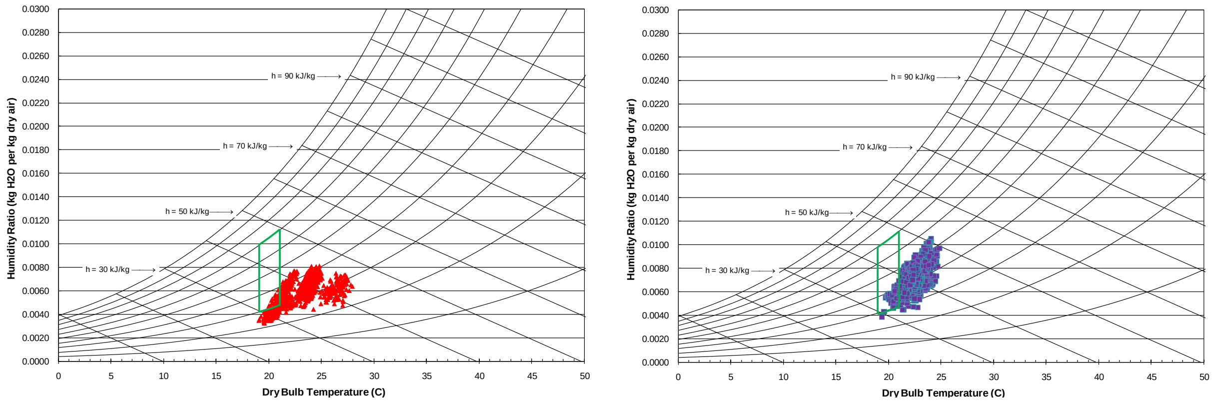


Figure 41: January classroom temperature & relative humidities: PHKG (left), SKG (right).

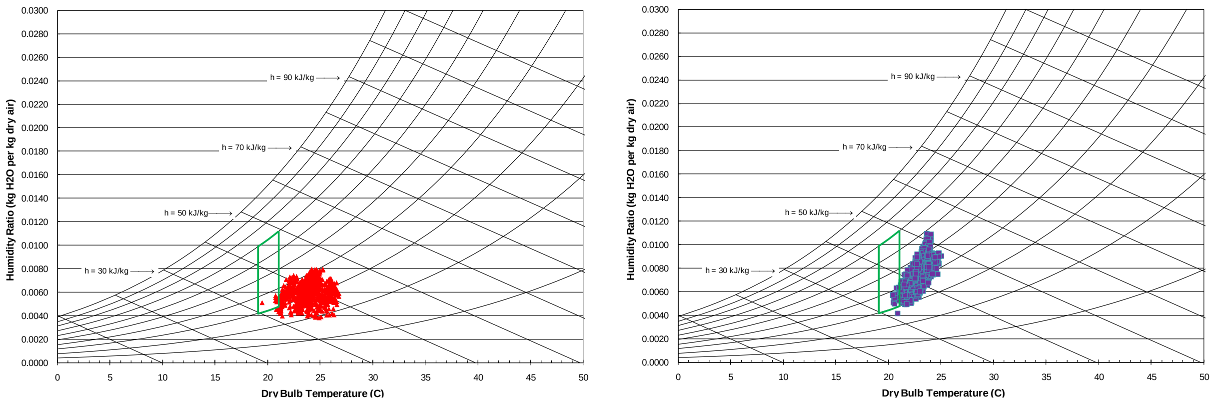


Figure 42: February classroom temperature & relative humidities: PHKG (left), SKG (right).

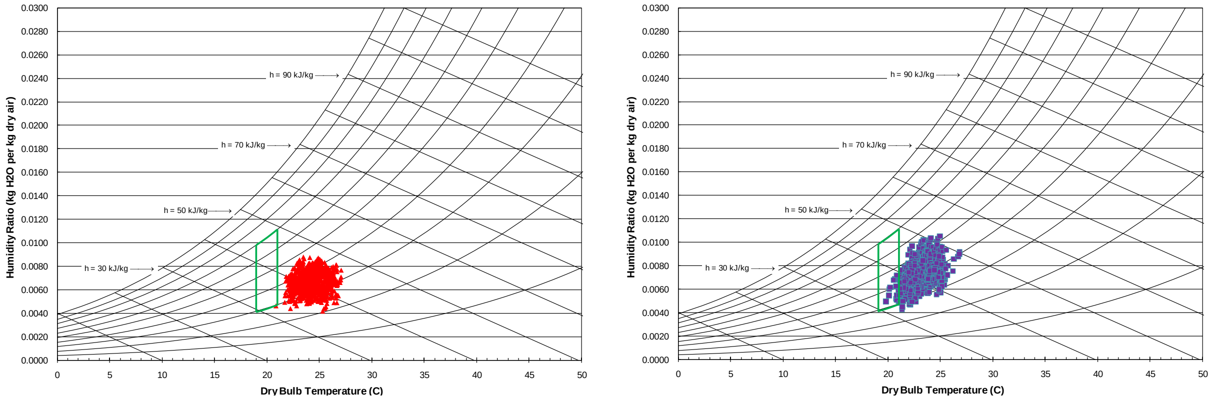


Figure 43: March classroom temperature & relative humidities: PHKG (left), SKG (right).

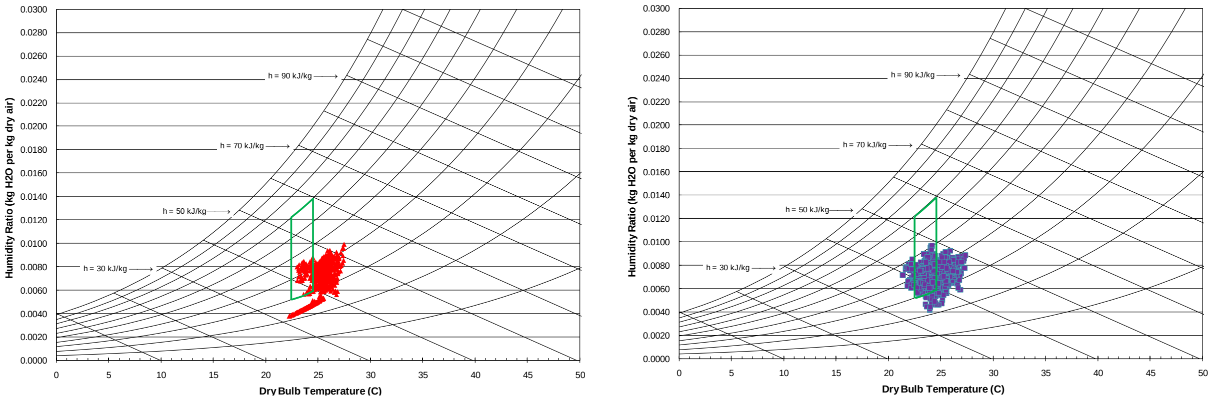


Figure 44: April classroom temperature & relative humidities: PHKG (left), SKG (right).

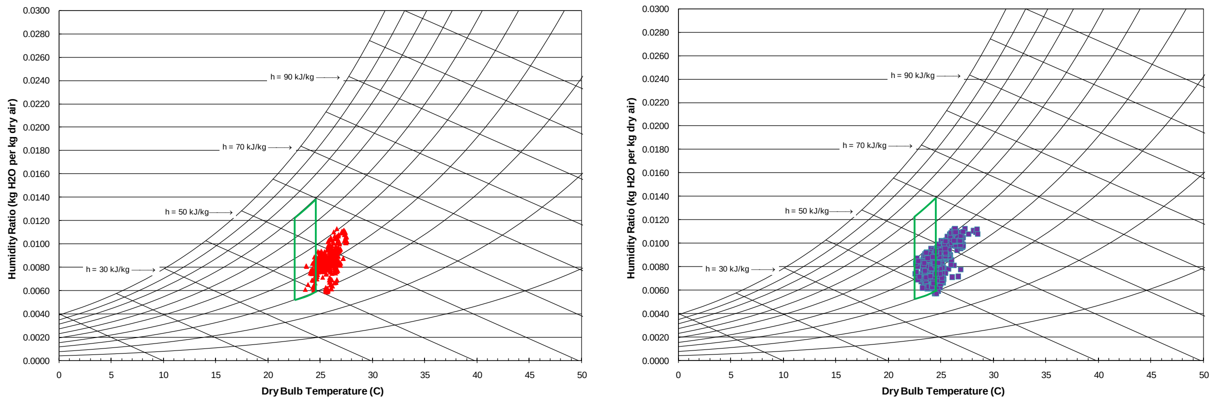


Figure 45: May classroom temperature & relative humidities: PHKG (left), SKG (right).

Table 13 shows the number of points that meet the comfort criteria as outlined by the ÖNORMS. The majority of the temperatures in both kindergartens are higher than what is defined as comfortable in the ÖNORMS for all months except in April and May, where the SKG has over 40% the temperature and relative humidity points within the acceptable boundaries of comfort.

Table 13: Percentage of temperature vs. relative humidity points within the set point criteria following ÖNORM EN ISO 7730 and ÖNORM EN 13779.

Month	PHKG [%]	SKG [%]
December	9.1	11.8
January	5.1	8.4
February	0.8	0.8
March	0.0	1.0
April	10.0	42.3
May	7.6	45.7

Especially in the PHKG, a low percentage of the points meet the ÖNORM criteria. There is a general tendency for temperatures to be constantly warmer in both kindergartens. As seen in the questionnaire responses in Section 5.6, the staff of both kindergartens also found temperatures to generally be too warm. Therefore, there is agreement between the recorded temperatures and user perceptions.

5.4. Indoor Air Quality

Indoor air quality (IAQ) was determined by measuring carbon dioxide concentrations. The results of the IAQ analysis are discussed in Sections 5.4.1 to 5.4.3.

5.4.1. Overall Carbon Dioxide Levels

The acceptable limits of carbon dioxide in classrooms are calculated using the outdoor concentration as a reference. The indoor concentration should be no more than 500 ppm over outdoor carbon dioxide levels in order to meet Category II requirements of the standard (ÖNORM EN 13779, 2007). Sigrist states that outdoor carbon dioxide levels normally average 370 ppm in the countryside to 700 ppm for polluted city air (Sigrist, 2004). Using these values, the acceptable indoor values for indoor carbon dioxide concentration is 1,050 ppm to 1,200 ppm. However, the European Collaborative Action has found that carbon dioxide concentrations should be lower than 1,000 ppm as higher carbon dioxide concentrations affect concentration and fatigue. The ventilation system in the PHKG is designed to keep carbon dioxide levels below 1,000 ppm (Reinberg, Energiesparkonzept Schukowitzgasse, 2005). Thus, the upper carbon dioxide concentration limit for the purpose of this study is set at 1,000 ppm. Figure 46 illustrates the overall carbon dioxide concentrations in both kindergartens.

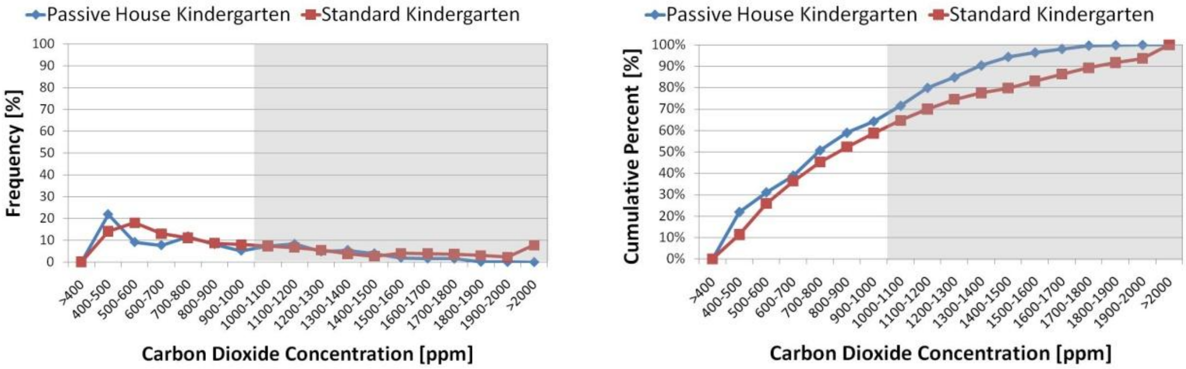


Figure 46: Carbon dioxide levels in the occupied classrooms for the observation period: CO2 bins (left), cumulative CO2 distribution (right).

The PHKG remains below 1,000 ppm 7% longer than the SKG, indicating that the indoor air quality is generally better in the PHKG. This is possibly due to the constant air exchange by the ventilation system. However overall, the carbon dioxide concentration is over the acceptable range for a large portion of the occupied period in both kindergartens: 32% of the time in the PHKG, and 39% in the SKG. The range of acceptable values is seen in the unmasked portion of Figure 46.

It has been found that the indoor air quality of classrooms is amongst the poorest of all building types, as windows are only opened during recesses and breaks, and left closed during lessons and outside of school hours (Hellwig, Antretter, Holm, & Sedlbauer, 2009). Classrooms also have one of the highest acceptable densities of all occupation types. Other room types with similar occupancies, aside from seminar rooms, are in use for shorter periods of time.

The tendency of the SKG to exceed 2,000 ppm when occupied for such a large portion of the time will be analyzed more closely in the monthly graphs in Section 5.4.2. Figure 47 illustrates the carbon dioxide levels in the unoccupied classrooms for the study period.

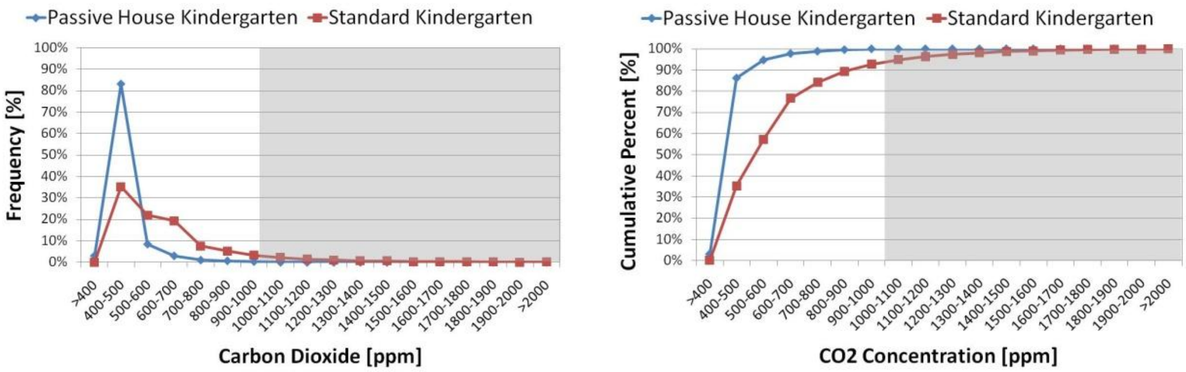


Figure 47: Carbon dioxide levels in the unoccupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

Comparing the cumulative percentage graphs of the occupied to unoccupied classrooms, the influence of people in the rooms is obvious (Figures 46 & 47). The pattern is clearly visible in the unoccupied cumulative percentage graph indicating that the PHKG has lower carbon dioxide levels because of constant air circulation from the ventilation system. The majority of PHKG values are 500 ppm and the SKG has more than 90% of values lower than 1,000 ppm.

5.4.2. Monthly Carbon Dioxide Results

A large fraction of the December carbon dioxide values remains below 500 ppm in the PHKG, whereas a large portion of the values in the SKG remain between 700 and 1,200 ppm (Figure 48). In comparison to the following months, January and February, the December carbon dioxide values are lower (Figures 48 to 50). The lower carbon dioxide levels may be partially attributable to the fact that the PHKG is unoccupied after December 24th as the ventilation system continues to extract indoor air while the PHKG is unoccupied during the Christmas holidays. The SKG was in operation with regular hours for a longer period of time, only closing on the 25th and the 29th of December.

Table 14 shows that the poorest IAQ occurs in both kindergartens during January and February. The SKG experiences carbon dioxide concentrations greater than 2,000 ppm in these months. The PHKG never exceeds carbon dioxide concentrations of 2,000 ppm during the study.

Table 14: Carbon dioxide concentration above 1,000 ppm.

Month	PHKG [%]	SKG [%]
December	13.9	22.6
January	51.7	74.5
February	61.0	78.3
March	41.6	55.3
April	4.1	4.4
May	8.3	6.2

There is a lower carbon dioxide concentration in March (Figure 51). April and May values start to strongly resemble the unoccupied curves, and both kindergartens have almost identical distributions of values (Figures 52 & 53). Questionnaire results indicate that both kindergartens begin to ventilate by opening windows for longer than three hours per day in April and May which is also clearly reflected in Figures 52 & 53.

The percentage of time that the carbon dioxide levels exceed 1,000 ppm illustrates that the PHKG achieves the intended IAQ levels between 39% and 96% of the time, depending upon the month (Figures 48 to 53). As the current kindergarten population of 235 people exceeds the designed occupancy by over 40%, it is possible that the ventilation system is undersized for the current occupancy and therefore cannot achieve the designed IAQ. See Figures 48 to 53 for the monthly carbon dioxide breakdowns.

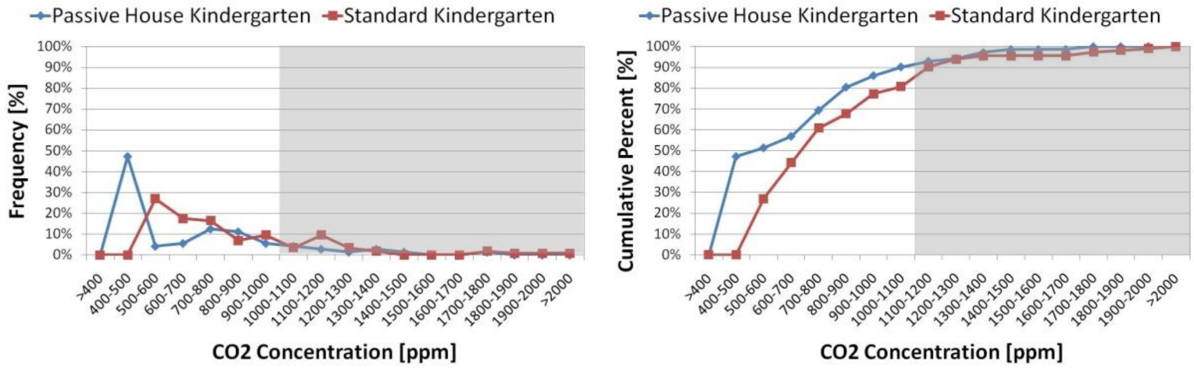


Figure 48: December carbon dioxide concentrations in the occupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

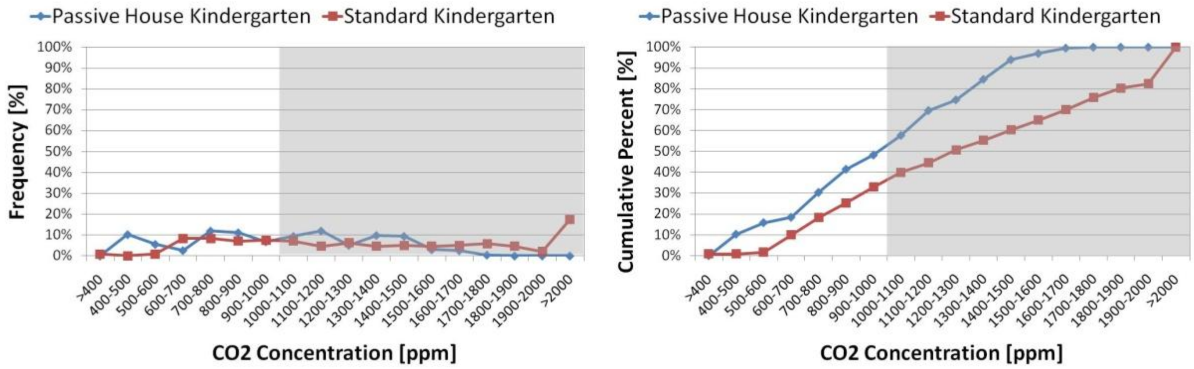


Figure 49: January carbon dioxide concentrations in the occupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

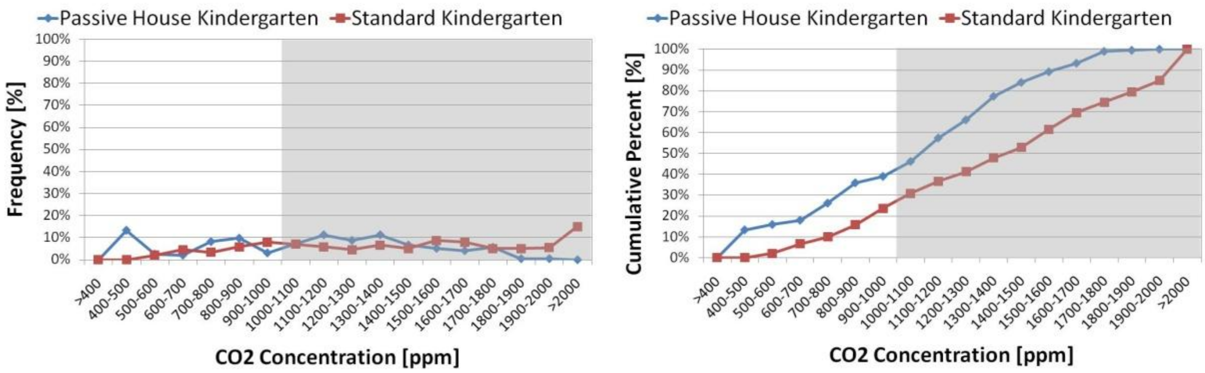


Figure 50: February carbon dioxide concentrations in the occupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

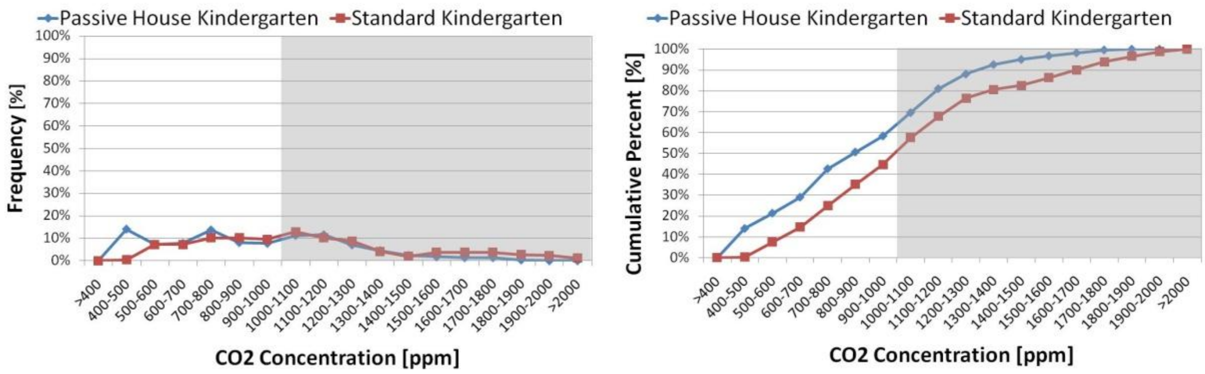


Figure 51: March carbon dioxide concentrations in the occupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

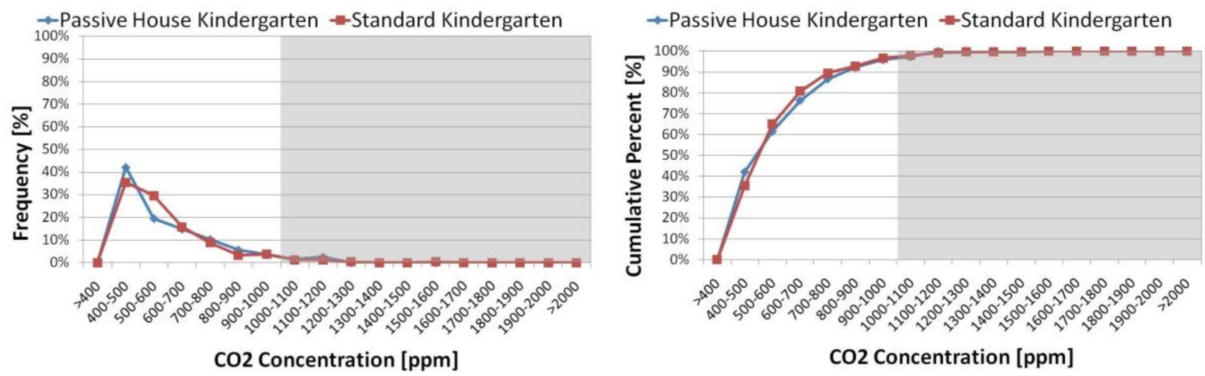


Figure 52: April carbon dioxide concentrations in the occupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

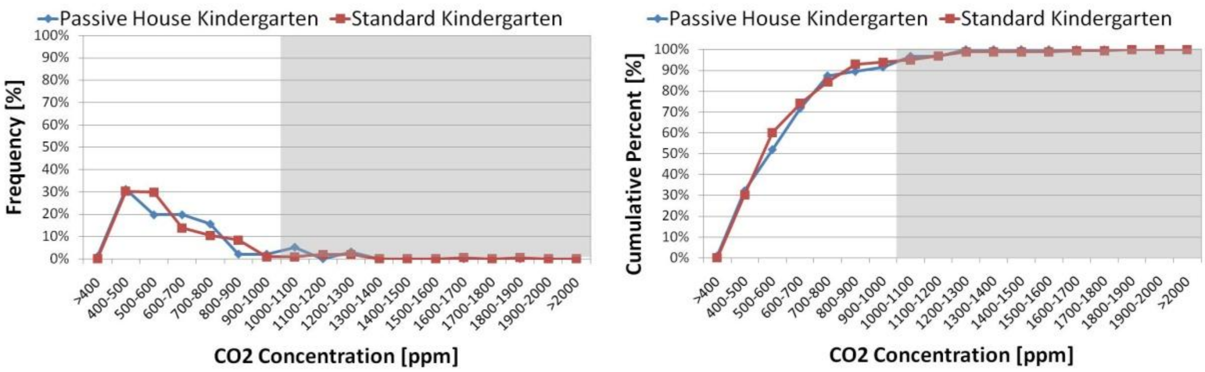


Figure 53: May carbon dioxide concentrations in the occupied classrooms: CO2 bins (left), cumulative CO2 distribution (right).

5.4.3. Weekly Carbon Dioxide Examples

The sharp valleys indicate when occupants open windows for natural ventilation. Figures 54 and 55 show consistent daily peaks above 1,700 ppm in the SKG, where users open windows infrequently due to cold exterior temperatures. The carbon dioxide levels fall significantly in May, remaining within recommended levels as users open windows for more than three hours per day in both kindergartens. The daily pattern of carbon dioxide concentrations is visible in Figures 54, 55, and 56 which depict the concentration differences in winter, early spring, and late spring.

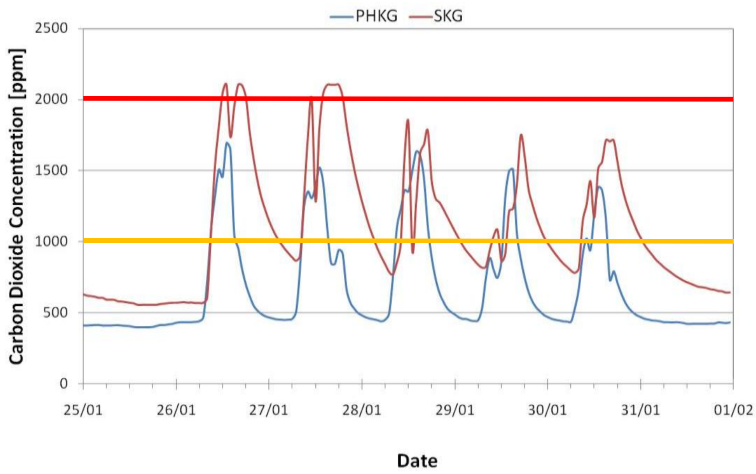


Figure 54: Carbon dioxide levels in the occupied classrooms: January 25th to 31st, 2008.

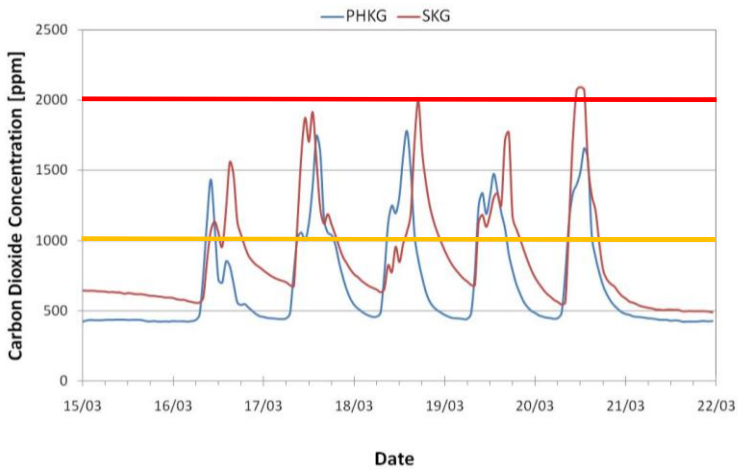


Figure 55: Carbon dioxide levels in the occupied classrooms: March 15th to 22nd, 2008.

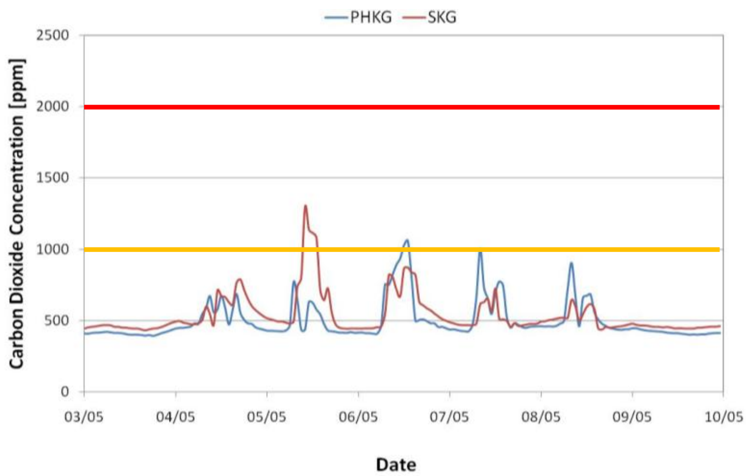


Figure 56: Carbon dioxide levels in the occupied classrooms: May 3rd to 10th, 2008.

5.5. Predicted Mean Vote & Predicted Percentage of Dissatisfied

The acceptable range of values is from -0.5 to 0.5 representing an environment that ranges from being very slightly cool to very slightly warm, and is shown as the unmasked portion in Figures 57 to 63.

Satisfaction with thermal conditions is slightly higher in the SKG classrooms, which shows more data points within the acceptable zone. The PMV values as seen in Figure 57 estimate that users will find both kindergartens to be slightly warm in all classrooms for the majority of time during study period.

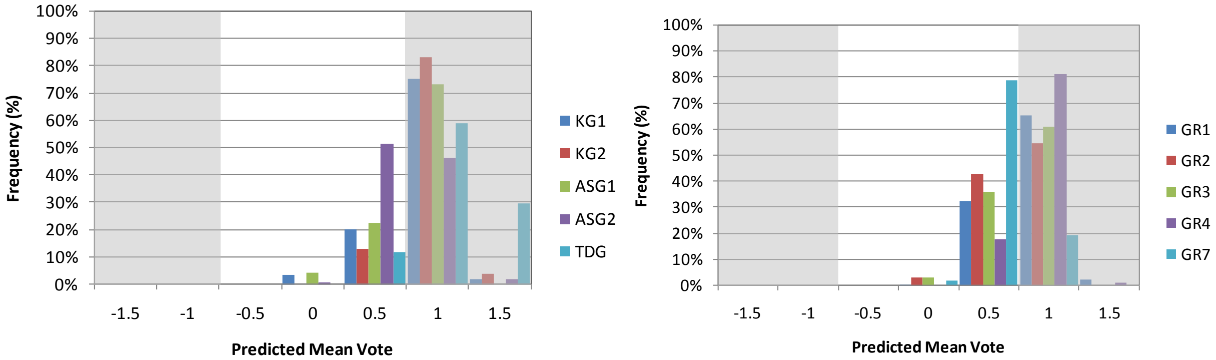


Figure 57: PMV for the observation period, PHKG (left), SKG (right).

5.5.1. Monthly PMV Analysis

The predicted perception of thermal comfort is consistent in both kindergartens; with values remaining clustered around 1, “slightly warm”. The estimated most comfortable month in the PHKG is December, and in the SKG, January (Figures 58 & 59). However, January has the highest portion of neutral values in the PHKG, and December shows the highest percentage of neutral values in the SKG.

When considering individual classrooms, the Toddler Group is predicted to be the warmest of all the occupied rooms, especially in January, February, March, and May (Figures 59, 60, 61, and 63).

PMV results correlate to the consistently warm measured indoor temperatures seen in Sections 5.2 and 5.3. The predicted comfort levels are compared to the actual users’ questionnaire results in Section 5.6.2.

The predicted percentage of dissatisfied, PPD, is shown in Table 15.

Table 15: Percentage of Persons Dissatisfied.

	PHKG					SKG				
	KG1	KG2	ASG1	ASG2	TDG	GR1	GR2	GR3	GR4	GR7
December	7.6	8.3	7.5	5.4	10.9	11.7	7.7	8.1	13.8	8.6
January	10.6	12.9	10.8	6.7	28.3	11.1	9.2	9.0	11.4	6.9
February	14.1	14.0	14.5	7.4	22.6	10.7	11.9	12.0	14.2	7.9
March	14.5	22.2	15.5	10.9	24.1	11.4	12.8	13.2	18.1	7.9
April	15.3	17.2	-	20.3	10.1	16.4	9.7	10.6	15.4	8.8
May	22.1	21.8	-	15.0	25.1	18.2	13.0	15.0	14.8	12.9
Period Average	14.0	16.1	12.1	10.9	20.2	13.2	10.7	11.3	14.6	8.8

In Table 15, the predicted PPD is shows a greater overall range in the PHKG than the SKG. The highest dissatisfaction level is in the PHKG Toddler's Group, and the PHKG After School Group 2 displays the lowest level of dissatisfaction. Dissatisfaction levels are generally predicted to increase as the weather becomes warmer in the PHKG. There is also a weaker tendency for dissatisfaction levels to increase in the SKG over time. Figures 58 to 63 illustrate the calculated monthly thermal comfort.

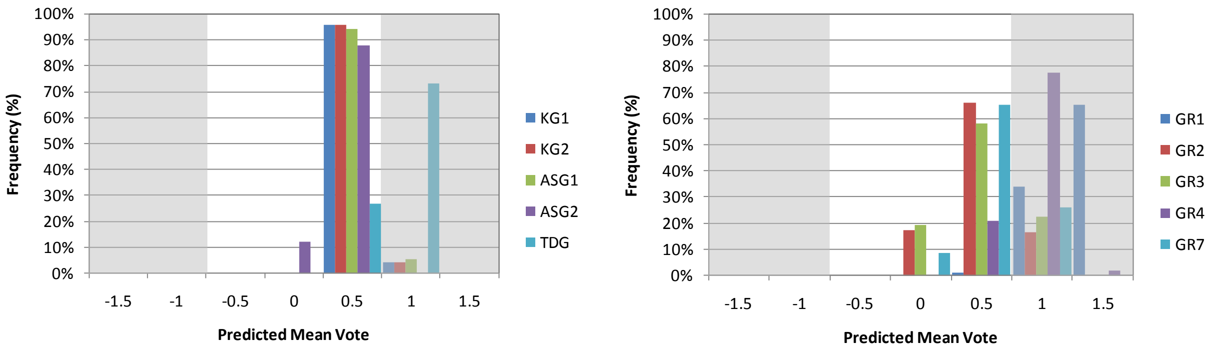


Figure 58: PMV for December, PHKG (left), SKG (right).

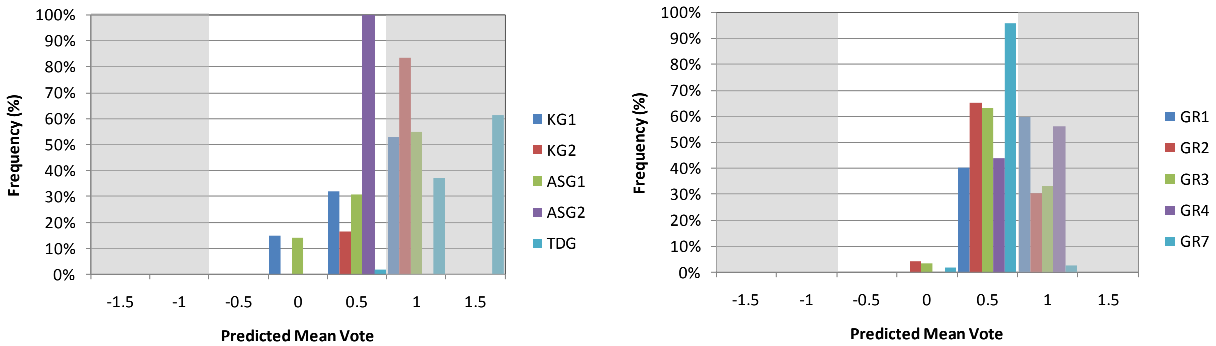


Figure 59: PMV for January, PHKG (left), SKG (right).

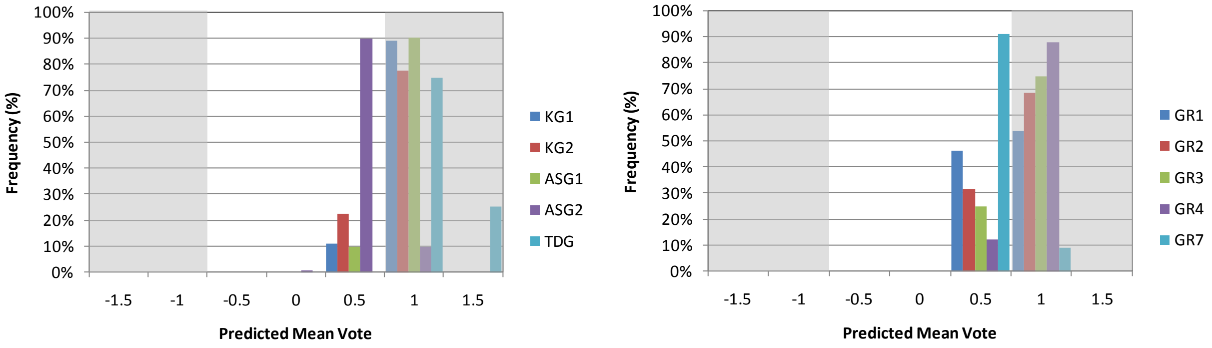


Figure 60: PMV for February, PHKG (left), SKG (right).

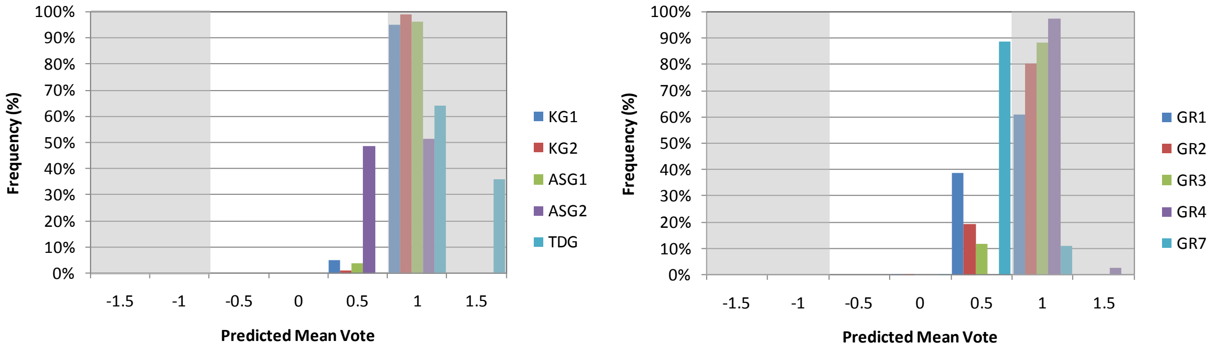


Figure 61: PMV for March, PHKG (left), SKG (right).

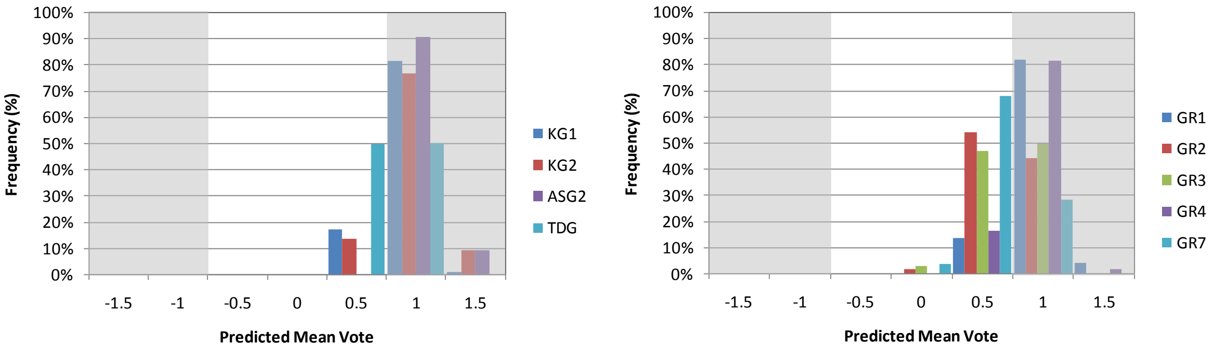


Figure 62: PMV for April, PHKG (left), SKG (right).

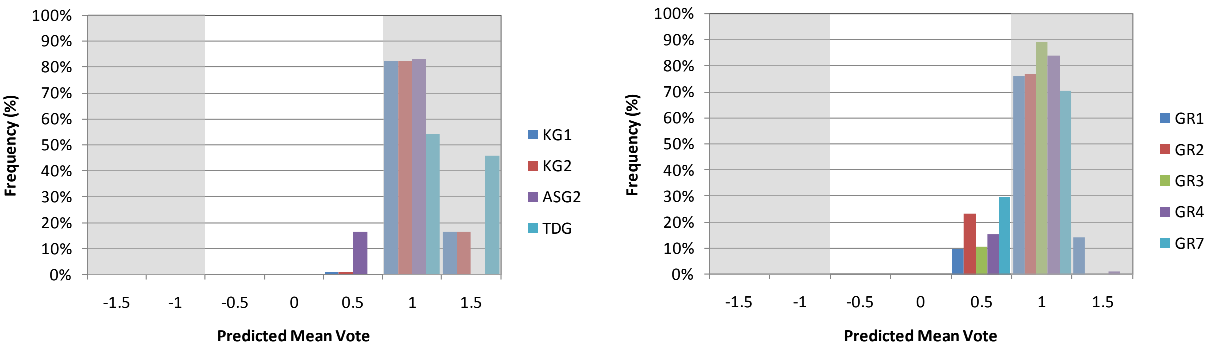


Figure 63: PMV for May, PHKG (left), SKG (right).

5.6. Questionnaire Results

5.6.1. Participant Demographics

In total, there were 27 participants from the PHKG, and 19 from the SKG. All respondents were female as visible in Figure 64.

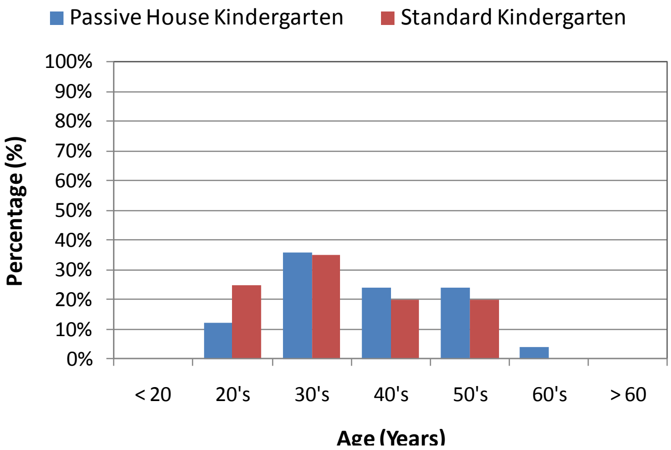


Figure 64: Age demographic of participants.

The PHKG generally has an older population; however, the majority of respondents in both groups are in their 30’s.

The interviewees responded with two job description types: Kindergarten Teachers and Assistants. There is a slightly larger population of teachers in relation to assistants in each group as seen in Table 16.

Table 16: Breakdown of staff responsibilities in the kindergartens.

		PHKG [%]	SKG [%]
Job Title:	Kindergarten Teacher	61.5	52.6
	Kindergarten Assistant	38.5	47.4

The majority of the population of kindergarten teachers and assistants have completed their O-Levels, as evident in Figure 65.

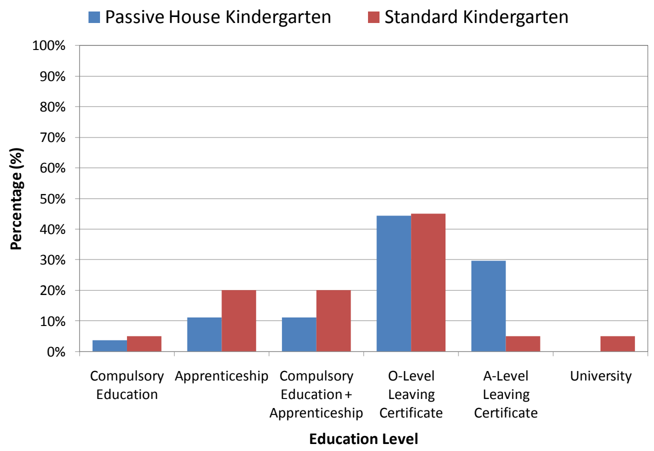


Figure 65: Education demographic of participants.

The majority of interviewees work full-time in both kindergartens as seen in Figure 66.

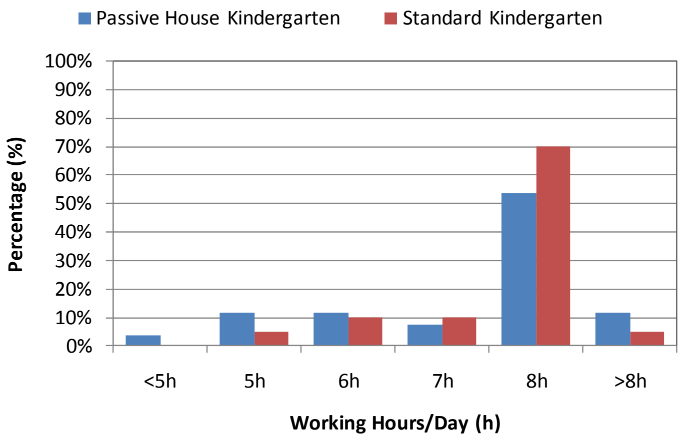


Figure 66: Interviewee working hours/day.

As seen in Figure 67, a large portion of the staff at the PHKG has been working at the kindergarten since the doors opened in 2006. It is also possible that a large portion of the SKG staff have been working since the kindergarten began operation six years previous.

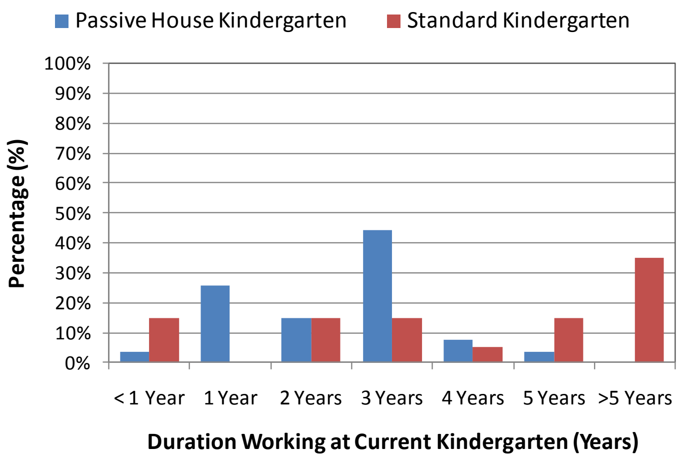


Figure 67: Period of time working at kindergarten.

Almost all the staff work with the children. In each case, there was one respondent who did not claim to work directly with the children. It is assumed that the kindergarten principals have included themselves as teachers, as they are the only staff members who do not work directly with them. See Figure 68 below.

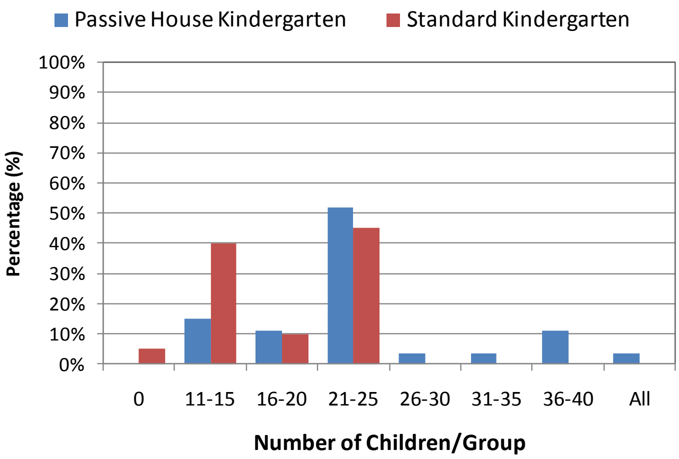


Figure 68: Number of children/kindergarten group.

The SKG have kindergarten groups that range between 11-25 children. The PHKG has a wider range variance of children in kindergarten groups; however, the dominant number is within the range of 21 to 25 children. See Table A-1 in Appendix 8.2.2 for the actual breakdown of demographic results.

5.6.2. Thermal Comfort

The questionnaire results relating to thermal comfort are shown in Table 17 below.

Table 17: Users' perception of thermal comfort in the kindergartens.

		PHKG [%]	SKG [%]
Length of time windows are opened per day:			
Summer	Never	0.0	0.0
	30 minutes	11.1	0.0
	1 hour	7.4	0.0
	3 hours	**48.1**	10.0
	>3 hours	33.3	**90.0**
Winter	Never	3.7	0.0
	30 minutes	33.3	17.6
	1 hour	**44.4**	**64.7**
	3 hours	11.1	11.8
	>3 hours	3.7	5.9
Users' assessment of indoor air quality:	Very good	0.0	0.0
	Good	14.8	36.8
	Neutral	**40.7**	15.8
	Bad	**40.7**	**42.1**
	Very bad	3.7	5.3
Users' satisfaction with ventilation possibilities:	Very satisfied	0.0	15.0
	Satisfied	11.1	25.0
	Neutral	37.0	**30.0**
	Slightly dissatisfied	**48.1**	25.0
	Dissatisfied	3.7	5.0
Users' average kindergarten winter room temperature assessment :	**Cold**	**33.3**	0.0
	Cool	14.8	15.0
	Neutral	11.1	10.0
	Warm	29.6	**65.0**
	Hot	11.1	10.0
Users' average kindergarten winter indoor humidity assessment :	Humid	0.0	0.0
	Somewhat humid	3.7	0.0
	Neutral	22.2	**35.0**
	Somewhat dry	29.6	**35.0**
	Very dry	**44.4**	25.0
Users' satisfaction with the heating system:	Very satisfied	0.0	10.0
	Satisfied	7.4	15.0
	Neutral	**33.3**	**40.0**
	Slightly dissatisfied	**33.3**	25.0
	Dissatisfied	25.9	5.0
Users' satisfaction with the ventilation system:	Very satisfied	0.0	0.0
	Satisfied	3.7	0.0
	Neutral	22.2	**15.0**
	Slightly dissatisfied	**44.4**	5.0
	Dissatisfied	25.9	0.0

Table 17 shows that occupants in both kindergartens opened windows for three or more hours for the majority of the time in summer. The influence is clearly seen in Section 5.4.2, which discusses the monthly IAQ. In comparison, windows are open for one hour or less in the winter months, which is reflected in the monthly IAQ results. It is not surprising that the subjective IAQ assessment for the PHKG has an equal number of questionnaire responses for “Ok” and “Bad”, as it would depend upon the time of year that the individual would be referring to. Similarly, the SKG has an almost equal split between responses “Good” and “Bad” probably also due to the season the individual was referring to.

Many of the questionnaire comments in the PHKG also relate to poor air quality. Eight of 11 respondents or over 72% complained directly about insufficient levels of fresh air. Two comments related to warm temperatures, one attributing the temperature to a large number of children, and another noting that the classroom becomes too warm due to summer solar irradiation. The last comment complained about headaches and increased dust, which also indirectly relates to IAQ.

In comparison, the SKG also had a high number of complaints of poor IAQ with seven of nine, or 78% of the comments relating to IAQ. There are more complaints about warm temperatures, with four of nine, or 44% of comments describing issues with IAQ. See Section 8.2.2, A-1 for the actual responses. Referring back to the temperatures observed in the kindergartens in the graphs of Section 5.2.1, it is seen that occupants of the SKG find 24°C too warm, especially in the summer months.

The majority of PHKG respondents were slightly dissatisfied with the ventilation possibilities, and a little less than half of those asked, 13 of 27, posted comments. Two respondents stated that room temperatures were always too high unless windows were opened, and that either there was too much or too little cross-ventilation. Small window size was commented by two, and that more windows for ventilation are needed. There was also general dissatisfaction with the IAQ.

Although SKG respondents were more or less satisfied when filling out the questionnaires, all four submitted comments about ventilation showing that there was too little air exchange.

The perception of indoor temperature in winter indicates that the PHKG respondents are almost evenly split between feeling cold and warm; whereas in the SKG, respondents were more consistent in their answers and dominantly perceived the temperatures to be too warm. The large portion of PHKG respondents who perceive cold temperatures seems to contradict the previous comments of feeling warm when asked about ventilation rate. The discrepancy may be explained by the distribution of respondents in different rooms with varying temperatures outside of what has been measured in the study, or responses may have been influenced by the season the questionnaire was answered (spring and summer 2009). When looking at the weekly temperature variance in the box plot analysis in Appendix 8.3, it is seen that the minimum temperature in the classrooms reaches 19°C in three of the classrooms in the week prior to the Christmas Break, and the two weeks following the holidays, the temperatures remain low in the classrooms with an average temperature below 21°C. However, in the week of January 15th to 21st, average temperatures are above 23°C in all measured classrooms aside from After School Group 2, which has an average temperature of 21.7°C. See Appendix 8.3 for the box plot graphs.

The responses of the PHKG questionnaires reflect that users actually felt cold, whereas the PMV in Section 5.5 predicts that users will be slightly warm. The PMV in the SKG shows greater consistency where users reported feeling warm.

Responses to air humidity were more consistent in the PHKG with the majority of responses stating that the indoor air is very dry. During the winter season, indoor humidities ranged from 19% to 44%, with lowest humidities occurring during January and February as seen in the monthly humidity bin diagrams in Section 5.2.6. Staff in the SKG stated greater satisfaction with humidity levels, which also reflects the recorded higher humidities in the SKG classrooms.

The majority of PHKG responses were either dissatisfied or slightly dissatisfied with the ventilation options correlating with the overall dissatisfaction with ventilation possibilities. The SKG does not have a mechanical ventilation system.

5.6.3. Health

Table 18 summarises the responses given to health-related issues. Especially in winter, lower indoor humidities often lead to sore throats and possibly headaches. The reported frequency of colds is lower in the PHKG, and that the incidence of allergies is also lower. There were no incidences of frequent nose bleeds noted in the PHKG despite complaints of dry air. However, the frequency of sore throats in both kindergartens is quite high. The subjective assessment of dry air in winter is consistent with the responses to the health questions. Headaches may possibly be an indication of poor indoor air quality, and inadequate lighting levels. Both kindergartens reported that headache frequency was low.

Table 18: Health complaints by users.

		PHKG [%]	SKG [%]
Health complaints by children:			
Colds	**Often**	**77.8**	**100.0**
	Sometimes	14.8	0.0
	Seldom	7.4	0.0
	Never	0.0	0.0
Headache	Often	14.8	15.0
	Sometimes	25.9	15.0
	Seldom	**44.4**	**30.0**
	Never	0.0	10.0
Allergies	**Often**	11.1	**45.0**
	Sometimes	**37.0**	25.0
	Seldom	33.3	15.0
	Never	3.7	0.0
Sore throat	**Often**	**59.3**	**45.0**
	Sometimes	22.2	15.0
	Seldom	14.8	15.0
	Never	0.0	0.0
Nose bleeds	Often	0.0	15.0
	Sometimes	29.6	**40.0**
	Seldom	14.8	25.0
	Never	**40.7**	0.0

5.6.4. Water Use

The location and frequency of laundry drying affects the overall indoor humidity in the kindergartens. As the laundry is hung in the Laundry Room in the PHKG, it does not contribute significantly to overall room humidity in the common spaces. In comparison, laundry is hung in the hallway of the SKG, and as indicated in the questionnaires, laundry is washed up to four times per day, which most likely assists in increasing overall indoor humidity levels. See Table 19 for a breakdown of water use in the kindergartens.

Table 19: Water use in the kindergartens.

		PHKG [%]	SKG [%]
Weekly frequency of cooking in the kindergarten:	**0**	**38.9**	**66.7**
	1-2	0.0	20.0
	3-4	0.0	6.7
	5-6	33.3	6.7
	7-8	11.1	0.0
	9-10	16.7	0.0
Weekly frequency of dishwasher use in the kindergarten:	0-5	4.2	0.0
	6-10	8.3	5.6
	11-20	8.3	**61.1**
	21-30	12.5	33.3
	31-40	**45.8**	0.0
	41-50	8.3	0.0
	Often	12.5	0.0
Weekly frequency of laundry washing:	1-2	0.0	0.0
	3-4	25	0.0
	5-6	**45.8**	6.3
	7-8	20.8	18.8
	9-10	0.0	18.8
	11-12	0.0	12.5
	13-15	0.0	12.5
	16-20	0.0	**31.3**
	Often	8.3	0.0
Method of laundry drying:	**Clothes dryer**	**100.0**	**100.0**
	Clothes drying rack	22.2	25.0
Location laundry is dried:	**Laundry Room**	**40.7**	0.0
	Clothes horse	3.7	15.0
	Hallway	0.0	**25.0**
	Atrium	0.0	10.0
	Group Cloakroom	0.0	5.0

As seen in Table 20, users in both kindergartens are generally satisfied with lighting in the kindergartens. There is a low frequency of headaches noted in Table 18, and general satisfaction with interior lighting levels.

Table 20: Users' assessment of lighting.

		PHKG [%]	SKG [%]
Users' assessment of daylight sufficiency in Kindergarten rooms:	Too much	3.7	5.0
	A little too much	37.0	30.0
	Sufficient	**59.3**	**60.0**
	Little	0.0	0.0
	Insufficient	0.0	5.0
Users' disturbed by direct sunlight:	Often	25.9	30.0
	Occasionally	**44.4**	**35.0**
	Seldom	29.6	**35.0**
	Never	0.0	0.0
Window shades used during the day:	**Often**	37.0	**65.0**
	Occasionally	**59.3**	30.0
	Seldom	0.0	5.0
	Never	3.7	0.0
Users' assessment of ease of external blind operation:	**Very easy**	**37.0**	0.0
	Easy	33.3	25.0
	Neutral	25.9	10.0
	Inconvenient	0.0	**60.0**
	Difficult	3.7	5.0
Users' assessment of artificial lighting in Kindergarten rooms:	Too much	7.4	5.0
	A little too much	33.3	15.0
	Sufficient	**59.3**	**75.0**
	Not much	0.0	5.0
	Insufficient	0.0	0.0
Lighting turned out at night:	**Yes**	**96.3**	**100.0**
	No	3.7	0.0

Table 21 exhibits general satisfaction with interior acoustics by questionnaire respondents. However, within the comments, respondents in the PHKG often noted that noise disturbances originated either from the children within their own group or neighbouring groups. Two complaints related to noise from the heat pump.

Table 21: Users' perceptions of acoustics in the kindergartens.

		PHKG [%]	SKG [%]
Users' disturbed by noise:	Often	25.9	10.0
	Occasionally	22.2	**30.0**
	Seldom	**37.0**	**30.0**
	Never	14.8	25.0
	N/A	0.0	5.0

In comparison, respondents in the SKG were disturbed from external noise sources such as street traffic or garden work and from multiple noise sources when the rooms had high occupancy.

5.7. Energy Analysis, Measured Values

The analyses focus upon the actual energy consumption as determined per kindergarten from the heating and electricity bills. A calculation was also performed to estimate monthly energy use in the kindergartens. See Appendix 8.4 for calculations.

5.7.1. Space Heating & DHW

The SKG has a district heating connection as its heating energy source. Both space heating and hot water are heated using district heating. Figure 69 shows metered energy use for space heating and DHW in the SKG (red) in comparison to the calculated energy profile (yellow). The second axis shows the monthly heating energy profile per square meter (green).

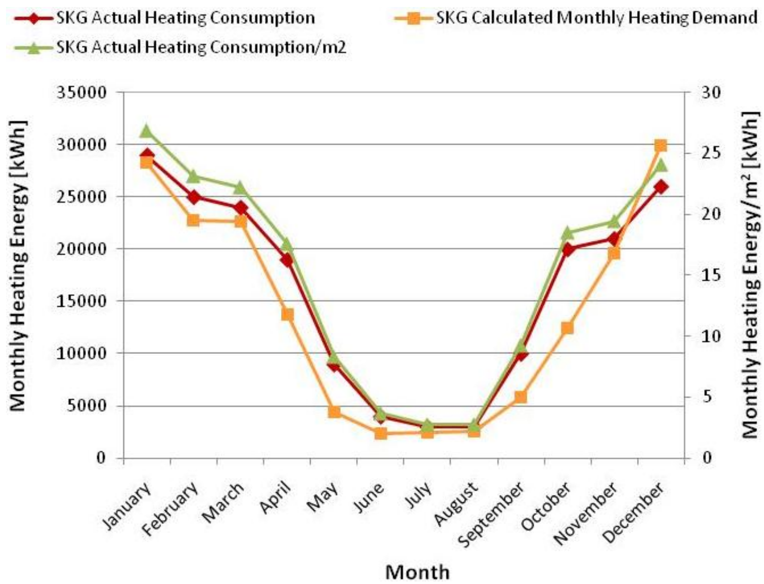


Figure 69: SKG actual heating consumption vs. calculated monthly heating energy.

It is not possible to make a direct comparison with the PHKG as the gas bills are recorded as a lump sum from February to September 2008. However, the nine month PHKG heating energy values were computationally derived using calculated monthly values of the heating energy demand to give a monthly profile for the year to compare heating energy use in both kindergartens per unit area. See Table A-8 for the calculation breakdown. Figure 70 illustrates the annual energy use profiles for the computationally derived PHKG values vs. the SKG actual values.

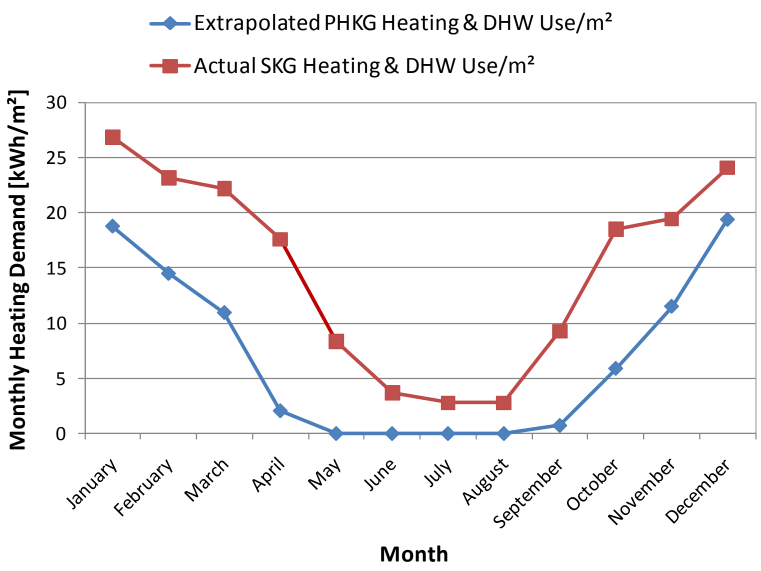


Figure 70: Heating energy use, space heating & DHW.

Table 22 summarizes the total energy use for the nine month period from January to September 2008 inclusive, and the total annual energy expenditures using the derived values for the PHKG.

Table 22: Actual heating energy use for space heating & DHW.

	PHKG [9 months]	PHKG [extrapolated annual]	SKG [9 months]	SKG [annual]
Total Heating Energy Use [kWh]	61,010.0	108,759.3	126,000.0	193,000.0
Gross Floor Area [m^2]	1,298.0		1,080.0	
Total Heating Energy Use/Gross Floor Area [$kWh/m^2 \cdot GFA$]	47.0	83.8	116.7	178.7

These data suggest that the PHKG uses 53% less energy annually than SKG for room and hot water heating (comparison based on extrapolated PHKG data).

5.7.2. Electricity

The difference between the two electrical consumptions is approximately 0.5 $kWh/m^2 \cdot month$, reflecting the standard monthly energy use of the ventilation system. The PHKG electricity use is also slightly higher due to the electricity needed for the solar panel circulation pumps. The energy use by both kindergartens follows a very similar pattern in visible in Figure 71 with a higher electrical load in the PHKG.

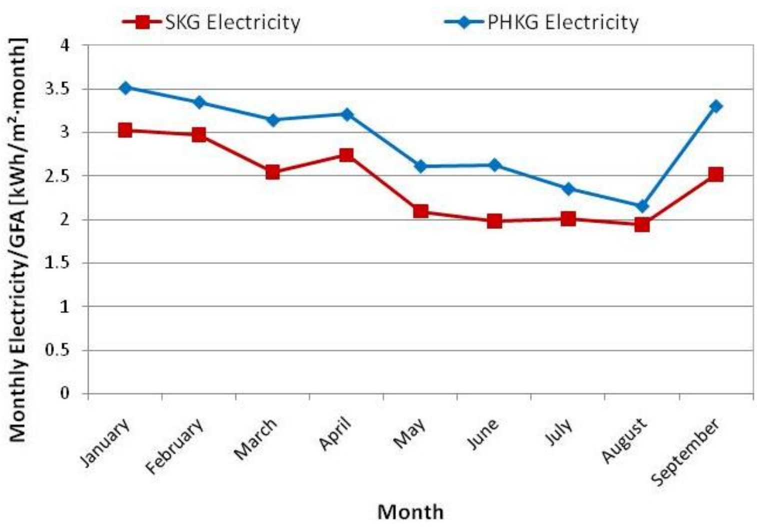


Figure 71: SKG & PHKG actual electricity consumptions.

Table 23 summarizes the overall electricity use for the nine month and annual periods. The annual values are derived based on Formula (8) found in Appendix 8.4.1. Actual values from the electricity bills are also found in Table A-9 of the appendices. Electrical energy use of PHKG is – according to the data presented – annually 9.3% higher than that of SKG (comparison based on extrapolated PHKG data).

Table 23: Actual electricity use.

	PHKG [9 months]	PHKG [extrapolated annual]	SKG [9 months]	SKG [annual]
Total Electricity Use [kWh]	30,897.0	41,309.3	22,639.0	31,479.0
Gross Floor Area [m^2]	1,298.0		1,080.0	
Total Electricity Use/Gross Floor Area [$kWh/m^2 \cdot GFA$]	26.3	31.8	21.8	29.1

Electrical consumption falls during the summer months in both kindergartens, possibly due to less use of interior lighting. The large window sizes of the SKG classrooms, especially those oriented to the southeast and southwest, and the south-oriented PHKG floor-to-ceiling classroom windows increase the amount of available daylight in both kindergartens.

5.7.3. Total Energy Use

The total energy use values combine the energy use from heating, DHW, and electricity. Values for the 9 month energy demand originate from the energy bills. When comparing the actual energy consumption values between kindergartens, the data suggests that the room heating and

DHW energy use of the PHKG is 42% (and overall energy use is 44%) less than SKG despite the increase in electricity consumption in the PHKG. Total energy use is summarized in Table 24.

Table 24: Actual total energy use.

	PHKG [9 months]	PHKG [extrapolated annual]	SKG [9 months]	SKG [annual]
Total Energy Use [kWh]	91,907.0	108,759.3	148,639.0	224,479.0
Gross Floor Area [m^2]	1,298.0		1,080.0	
Total Energy Use/Gross Floor Area [$kWh/m^2 \cdot GFA$]	70.8	115.6	137.6	207.9

5.8. Summary

Indoor classroom temperatures were constantly warmer than the set point temperatures outlined in the standards during periods of occupancy in both kindergartens with an average of 4K in the PHKG and 3K in the SKG. In the secondary rooms, the PHKG Children’s Toilet had a tendency to remain at 27°C and the Multipurpose Room in the basement of the SKG remained at 26°C.

Indoor humidity levels ranged from 30% to 40% in the PHKG which was 5% drier than the humidity levels recorded in the SKG which dominantly ranged from 40% to 45%. Of all the rooms, the Kitchens had the highest humidity levels, with humidity levels 5% higher than those recorded in other rooms. The lowest humidity levels in the PHKG were recorded during the winter months of January to March. The SKG had more constant monthly classroom humidities.

Psychrometric charts, merging both temperature and relative humidity data, indicated that the PHKG remains in the acceptable temperature and relative humidity parameters of the standard from 0% to 10% of the observation period; whereas the SKG meets the parameters 0.8% to 45.7% of the time reinforcing the findings in the previous sections that the PHKG experiences slightly lower winter humidity and warmer temperatures than the SKG, and that the Austrian Standard values do not correspond well with actual conditions.

Although IAQ was found to be better in the Passive House Kindergarten with 42.5% of measured values below 1,000 ppm in comparison with the Standard Kindergarten (64.7%), carbon dioxide levels still exceeded the acceptable level of 1,000 ppm in the cold months until windows in both buildings were left open for more than three hours per day in the warmer months of April and May. However, the PHKG showed a marked improvement in IAQ.

According to the Predicted Mean Vote calculations of ÖNORM EN 7730, it was estimated that users in both kindergartens would find interior temperatures neutral to warm for the entire observation period. The Percentage of Persons Dissatisfied calculations indicated higher satisfaction in the SKG in all months except for December with a tendency of increasing overall dissatisfaction with increasing temperatures.

Questionnaire results indicated that, amongst other things, users in the PHKG were split in their perception of temperatures as both warm (29.6%) and cold (33.3%), and that 65% of SKG respondents found temperatures to be warm. The perception of cold temperatures by PHKG users conflicts with the PMV and PPD estimates, and measured results. Each kindergarten classroom is populated by 23 to 27 people, 2 adults and 21 to 25 children, giving a population density of 2.1 m^2 to 2.4 m^2 per person. User responses showed that satisfaction with IAQ was higher in the PHKG indicated by satisfaction with the ventilation system (70.3%) and less frequent summer natural ventilation (33.3% ventilated more than 3 hours) than the SKG (90% ventilated more than 3 hours).

User satisfaction was higher in the Passive House Kindergarten. Because the winter set point temperature is higher than the design value of 22°C, the energy consumptions were higher than the initial calculations. The overall annual energy consumption of the PHKG is reduced by almost half, 44%, and heating demand by more than half, 53%, when compared to the measured results of the SKG.

6. Conclusions

6.1. Contributions

The Passive House Kindergarten uses a fraction of the heating energy and improves indoor air quality, especially in the winter months, when compared to the Standard Kindergarten.

However, it is questionable if the set temperatures reflect users' preferences as the questionnaire results indicated that three-quarters of the SKG users were too warm but almost half the PHKG users were too cool. There is a very poor correlation between the defined values in the standard and measurements for temperature and indoor humidity, all analyses indicating that temperatures are slightly high.

The presence of a ventilation system and solar panels increases overall electrical consumption in the PHKG, however, also significantly improves IAQ, especially in the winter months when natural ventilation rates were stated as lower than one hour per day. Natural ventilation rates of greater than 3 hours balance the indoor carbon dioxide concentration with outdoor levels.

Indoor conditions in both kindergartens can be further improved by balancing the temperature distribution in all rooms, and adjusting the set point temperature to users' preferences. The set point temperatures outlined in the Austrian standards do not meet with the expectations of the users in this study, nor the actual indoor running temperatures in both kindergartens.

6.2. Future Work

It was seen that more energy could be conserved with better regulation of the individual room temperatures while providing a comfortable indoor environment. The temperature in secondary and less used rooms was also observed to be within the same range of temperatures as the classrooms. It would be worthwhile to undertake further research and development into the effect of occupancy sensor-based building controls in learning environments for regulating heating, cooling, ventilation, and lighting systems for improving thermal comfort. Experiments such as the hybrid ventilation system with fuzzy logic controls by Steiger and Hellweg of the Fraunhofer Institute for Building Physics are developing new building automation techniques to regulate opening and closing windows for maintaining IAQ in schools (Steiger & Hellweg, 2010). Contributions taking into account refined ventilation controls related to carbon dioxide concentrations or occupancy could be developed further to reduce winter heat losses while maintaining IAQ levels.

As was seen from the energy analysis, an accurate user profile is needed to better determine electricity consumption in relation to thermal comfort in building calculations and simulations.

The user profile varies according to climate, occupancy, and cultural habits. The works of Gaceo, Vázquez, and Moreno have compiled a database of user profiles spanning over seven years and 700 Spanish residences (Gaceo, Vázquez, and Moreno, 2009). Developing a database of similar user profiles for schools in Austria would assist greatly in understanding user behaviour for refining the user profile used for accurately determining internal lighting and equipment loads in building simulations.

The PHKG utilized loam plaster as an interior finish. The impact of natural materials on IAQ, humidity regulation, and thermal storage would be an intriguing exploration.

Investigating the impact of site-related factors such as street noise, security, and level of user control for natural ventilation could potentially expand the body of knowledge of human interaction with their learning environment to establish thermal comfort.

6.3. Recommendations

Simple steps may improve IAQ, such as altering teachers habits to open windows for short five minute periods on a regular schedule throughout the day, e.g. when changing between activities or during lunch and snack breaks. Short regular airing aids to dissipate the accumulated carbon dioxide to the exterior. Airing would be beneficial in both kindergartens, especially in the SKG.

User satisfaction could be increased by proper commissioning of the ventilation system as part of the initial installation in the PHKG to ensure even temperature distribution and supply air volume. A post-occupancy review could give direct feedback to facility managers to determine if the temperature and ventilation volume set points meet user requirements. The calculations for the ventilation system supply air volume could be reviewed for the PHKG as the population is almost double what was initially expected. As part of the maintenance schedule, regular checks of air supply volume and temperature would also be helpful measures to ensure even distribution of indoor conditions.

To minimize noise disturbance from external sources, ground maintenance schedules could be coordinated to take place outside of quiet activities in the kindergarten, such as nap time.

To improve winter indoor humidity, especially in the PHKG, laundry may be dried in a central area if it does not interfere with kindergarten activities. The location and number of house plants may also contribute to improving winter indoor humidity levels.

The design set point temperatures in the Austrian Standards could also be reviewed for better concurrence with current research findings of user expectations of thermal comfort in kindergartens.

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7.2. List of Tables

7.3. List of Figures

7.4. Acknowledgements

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8. Appendices

8.1. Photos

8.1.1. Passive House Kindergarten Logger Locations

Figure A-1: Family Group, Quiet Area, logger placed on top of a bookshelf.

Figure A-2: Family Group, Main Area, logger on top of door frame.

Figure A-3: Family Group, Quiet Area, wall mounted CO_2 sensor.

Figure A-4: After School Group 1, logger placed on top of bookshelf.

Figure A-5: After School Group 2, logger placed on cabinet side.

Figure A-6: Toddler's Group, logger placed on shelf side.

Figure A-7: Kitchen, logger placed on top of kitchen cabinets.

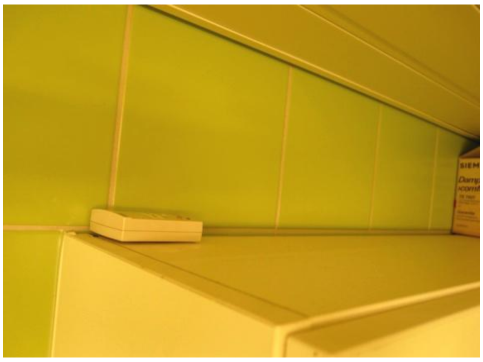


Figure A-8: Children's WC, logger placed on top of cabinet.

Figure A-9: Corridor, logger placed at door panel top.

Figure A-10: Staff Room, logger placed on bookshelf side.

Figure A-11: Atrium, logger placed at window frame top-left corner.

8.1.2. Standard Kindergarten Logger Locations

Figure A-12: Multipurpose Room, logger placed on shelf top.

Figure A-13: Group Room 1, logger located on cabinet side.

Figure A-14: Atrium, logger in window ope top-left corner.

Figure A-15: Group Room 2, logger on cabinet top.

Figure A-16: Staff Room, logger placed on top of lockers.

Figure A-17: Kitchen, logger on top of fire extinguisher.

Figure A-18: After School Group 4, CO_2 sensor and wall mounted temperature / humidity logger.

Figure A-19: Group Room 3, wall mounted logger.

Figure A-20: Group Room 7, wall mounted logger.

Figure A-21: Children's WC, logger on cabinet top.

8.2. Questionnaire

8.2.1. Blank Questionnaire

ALLGEMEIN

1. Geschlecht

   ○ männlich ○ weiblich

2. Alter

   ○ < 20 ○ 20er ○ 30er ○ 40er ○ 50er ○ 60er ○ +60er

3. Berufsbezeichnung: ____

4. Höchste abgeschlossene Ausbildung:

   ○ Pflichtschule ○ Lehre ○ Fachschule ○ Matura ○ Hochschule

5. Wie viele Stunden arbeiten Sie pro Tag im Durchschnitt? _______h

6. Wie lange arbeiten sie schon an ihrem jetzigen Arbeitsplatz? _______ Jahre

7. Arbeiten Sie mit den Kindern? ○ Ja ○ Nein

8. Wie viele Kinder sind in Ihrer Kindergruppe?

   ____

KOMFORT

9. Haben Sie ausreichend Tageslicht in den Aufenthaltsräumen im Kindergarten?

   ○ zu viel ○ etwas zu viel ○ geht so ○ wenig ○ unzureichend

10. Werden Sie durch direktes Sonnenlicht in den Innenräumen gestört?

    ○ ja häufig ○ gelegentlich ○ selten ○ nie

11. Aktivieren Sie tagsüber den Sonnenschutz?

    ○ ja häufig ○ gelegentlich ○ selten ○ nie

12. Können Sie die Jalousien leicht auf und zu machen?

    ○ sehr leicht ○ leicht ○ geht so ○ umständlich ○ geht nicht

13. Haben Sie ausreichend künstliche Beleuchtung in den Aufenthaltsräumen im Kindergarten?

    ○ zu viel ○ etwas zu viel ○ geht so ○ wenig ○ unzureichend

14. Ist die Beleuchtung in der Nacht ausgeschaltet? ○ Ja ○ Nein

KOMFORT

15. Wie lang sind die Fenster bei Ihnen pro Tag geöffnet? (falls Fenster offenbar)

	nie	*30 min*	*1 Std.*	*3Std*	*>3Std.*
Sommer	○	○	○	○	○
Winter	○	○	○	○	○

16. Beurteilen Sie die Luftqualität im Kindergarten:

○ sehr gut ○ gut ○ geht so ○ schlecht ○ sehr schlecht

Falls Sie „sehr schlecht" oder „schlecht" ankreuzen, geben Sie bitte an warum?

17. Sind Sie mit den Lüftungsmöglichkeiten im Kindergarten zufrieden?

○ sehr zufrieden ○ zufrieden ○ geht so ○ weniger ○ gar nicht

Falls Sie „gar nicht" oder „weniger" ankreuzen, geben Sie bitte an warum?

18. Beurteilen Sie die durchschnittliche Temperatur im Kindergarten im Winter:

○ kalt ○ eher kühl ○ neutral ○ eher warm ○ heiß

19. Beurteilen Sie die Luftfeuchtigkeit im Kindergarten im Winter:

○ feucht ○ etwas feucht ○ geht so ○ etwas trocken ○ sehr trocken

20. Wie zufrieden sind Sie mit der Heizung?

○ sehr zufrieden ○ zufrieden ○ geht so ○ weniger ○ gar nicht

21. Wie zufrieden sind Sie mit der Lüftungsanlage? (falls vorhanden)

○ sehr zufrieden ○ zufrieden ○ geht so ○ weniger ○ gar nicht

22. Werden Sie durch Lärm im Kindergarten gestört?

○ ja häufig ○ gelegentlich ○ selten ○ nie

Falls Sie „ja häufig" oder „gelegentlich" ankreuzen, geben Sie bitte die Lärmquelle(n) an?

GEWOHNHEITEN

23. Wie oft wird in Ihrem Kindergarten pro Woche gekocht? __________Mal
24. Wie oft sind die Geschirrspülmaschinen pro Tag im Einsatz? __________Mal
25. Wie oft wird in Ihrem Kindergarten pro Tag Wäsche gewaschen? __________Mal
26. Wie wird die Wäsche getrocknet? ○ Trockenmaschine ○ Wäsche wird aufgehängt
27. Wenn die Wäsche aufgehängt wird, wo hängen Sie sie auf? ______________________

GESUNDHEIT

28. Welche Beschwerden haben die Kinder im Kindergarten?

	häufig	selten	manchmal	nie
○ Erkältung	○	○	○	○
○ Kopfweh	○	○	○	○
○ Allergien	○	○	○	○
○ Halsschmerzen	○	○	○	○
○ Nasenbluten	○	○	○	○

○ Andere: Bitte beschreiben Sie: ____

____

____

____

____

____

____

Danke, dass Sie den Fragebogen ausgefüllt haben!

8.2.2. Questionnaire Analysis

Table A-1: Participant demographics.

		PHKG [%]	SKG [%]
Gender:	Female	100.0	100.0
	Male	0.0	0.0
Age:	20<	0.0	0.0
	20-29	12	25.0
	30-39	36	35.0
	40-49	24	20.0
	50-59	24	20.0
	60-69	4	0.0
Job Title:	Kindergarten Teacher	61.5	52.6
	Kindergarten Assistant	38.5	47.4
Highest completed education level:	Compulsory Education	3.7	5.0
	Apprenticeship	11.1	20.0
	Compulsory Education + Apprenticeship	11.1	20.0
	O-Level Leaving Certificate	44.4	45.0
	A-Level Leaving Certificate	29.6	5.0
	University	0.0	5.0
Length of average working day:	5h<	3.8	0.0
	5h	11.5	5.0
	6h	11.5	10.0
	7h	7.7	10.0
	8h	53.8	70.0
	>8h	11.5	5.0
Length of time working at current Kindergarten:	1< Year	3.7	15.0
	1 Year	25.9	0.0
	2 Years	14.8	15.0
	3 Years	44.4	15.0
	4 Years	7.4	5.0
	5 Years	3.7	15.0
	>5 Years	0.0	35.0
Work with children:	Yes	96.3	95.0
	No	3.7	5.0
Number of children/group:	0	0.0	5.0
	11-15	14.8	40.0
	16-20	11.1	10.0
	21-25	51.9	45.0
	26-30	3.7	0.0
	31-35	3.7	0.0
	36-40	11.1	0.0
	All	3.7	0.0

Table A-2: Questionnaire comments from the Question #16, user assessment of IAQ.

Comments - PHKG
Headache, increased dust.
Only one window is operable (for ventilation); It is very hot in summer from direct sunlight into the rooms through many windows.
25 children in the room. Too hot!
It is not possible to ventilate correctly with the ventilation system.
Little fresh air; often feel that the air is stale.
Little fresh air; poor air quality with a group of 25 children.
Insufficient ventilation possibilities.
Too little fresh air, unless it is ventilated (through open windows).
Fresh air quickly consumed.
With a large group of children, the air change rate is too low.
Very dry and stuffy, headaches and easily catch a cold.
Comments - SKG
It is far too warm in summer with no cooling possibility.
Very stuffy in winter and humid in summer.
Very hot and humid in summer.
Very hot in summer and sometimes stuffy when the blinds are down.
Smells of stale air with no cross-ventilation (draught).
No passage.
No draught.
A lot of stale air; one cannot ventilate well, either there is too much cross-draught or the children are disturbed.
Always too warm and stuffy.

Table A-3: Questionnaire comments from Question #17, user satisfaction with ventilation possibilities.

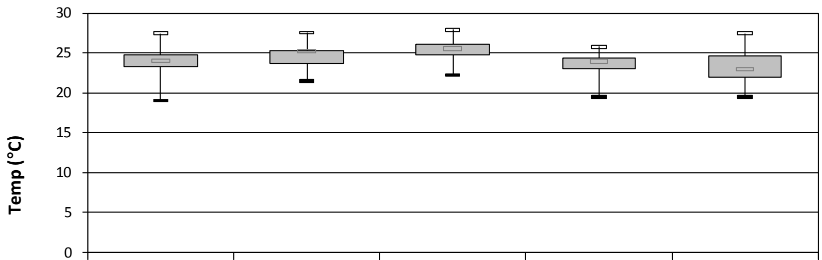
Comments - PHKG
Window must be opened for ventilation. Additionally, high room temperature, 27°C.
The room temperature is always too warm, 27°; the temperature is decreased only by opening the windows.
Too little fresh air.
Sometimes there is too much ventilation; ventilation system is very noticeable; window opes are too small.
In the corridor, the ventilation does not work because of the security system; bad planning.
Night filter or rather the air exchange is turned off because of the alarm system and only one window.
The window is too small to allow fresh air into the room. The children suffer from lack of oxygen (concentration, fatigue).
Air is quickly consumed; air circulation brings too little fresh air.
Through the ventilation system.
1 window.
Air circulation brings little.
Draught.
Ventilation system does not function adequately. When doors and windows are opened to aid ventilation, it draws the draught strongly through the rooms.
Comments - SKG
Too little ventilation.
No draught.
No draught.
A lot of stale air; one cannot ventilate well, either there is too much cross-draught or the children are disturbed.

Table A-4: Questionnaire comments from Question #22, user satisfaction with room acoustics.

<u>Comments - PHKG</u>
Children.
Noise of playing children.
When learning, children are disturbed by noise penetrating through the sliding glass door from the neighbouring group.
Because of the close proximity (or poor acoustic insulation) is noise from neighbouring groups sometimes disturbing.
Heat pump.
The corridor is not acoustically insulated. The noise level is like an airport.
The sliding doors let noise from neighbouring groups through - disturbing.
Heat pump.
Eating in the common space - loud. No acoustic insulation, only glass and metal.
Noise through the sliding doors. Common area - very loud.
The common area has poor acoustic insulation. Noise from children is often very high. The sliding doors often let noise from other groups through.
<u>Comments – SKG</u>
Disturbance by lawn mowing or other garden work during the daily nap between 12:00 and 14:30.
Noise disturbance from cars and trucks passing on the street.
Noisy when there are too many children in one room. The corridor resonates when many children play or when cars pass by.
Disturbance by workers in the adjacent office building and by garden work such as lawn mowing during the daily nap between 12:00 and 14:30.
Poor acoustics in individual group rooms when many people speak. Corridor has poor acoustics.

8.3. Box Plot Graphs

8.3.1. PHKG Summary & Weekly Box Plot Graphs

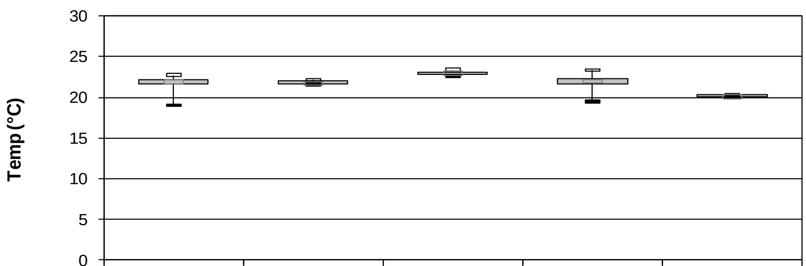


	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.3	23.7	24.7	23.0	22.0
Max	27.5	27.6	27.9	25.8	27.5
Min	19.0	21.5	22.2	19.5	19.5
Third Quartile	24.7	25.3	26.1	24.4	24.7
Median	24.0	25.3	25.6	23.9	23.0
	KG 1	**KG 2**	**Toddler's**	**ASG 1**	**ASG 2**

Figure A-22: PHKG classroom box plot and temperature breakdown for the study period.

	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	22.1	22.2	23.0	21.9	20.3
Max	22.9	22.7	23.3	22.8	21.3
Min	21.2	21.5	22.4	21.3	20.2
Third Quartile	22.6	22.5	23.2	22.4	21.0
Median	22.4	22.3	23.2	22.2	20.7
	KG 1	**KG 2**	**Toddler's**	**ASG 1**	**ASG 2**

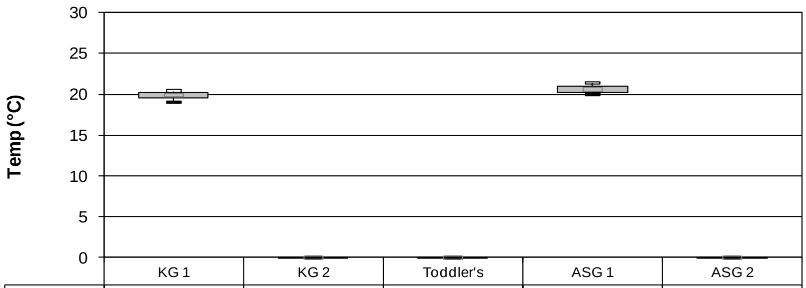
Figure A-23: PHKG box plot and temperature breakdown, Week 1.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	21.7	21.6	22.8	21.6	20.0
Max	22.7	22.2	23.4	23.3	20.3
Min	19.0	21.6	22.6	19.5	20.0
Third Quartile	22.2	22.0	23.1	22.2	20.3
Median	21.9	21.7	22.9	22.0	20.1
	KG 1	**KG 2**	**Toddler's**	**ASG 1**	**ASG 2**

Figure A-24: PHKG box plot and temperature breakdown, Week 2.

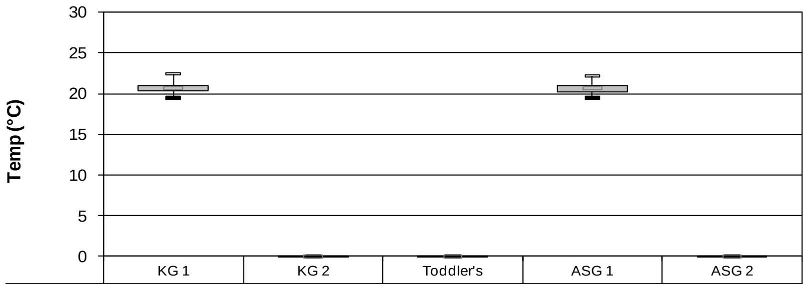
The kindergarten was closed for the 3rd week for Christmas holidays.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	19.5	0.0	0.0	20.2	0.0
Max	20.4	0.0	0.0	21.4	0.0
Min	19.0	0.0	0.0	20.0	0.0
Third Quartile	20.1	0.0	0.0	21.0	0.0
Median	19.9	0.0	0.0	20.6	0.0

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

Figure A-25: PHKG box plot and temperature breakdown, Week 4.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	20.3	0.0	0.0	20.2	0.0
Max	22.4	0.0	0.0	22.2	0.0
Min	19.5	0.0	0.0	19.5	0.0
Third Quartile	21.0	0.0	0.0	21.0	0.0
Median	20.7	0.0	0.0	20.7	0.0

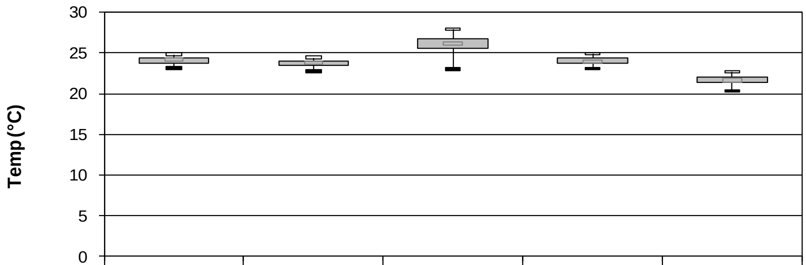
KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

Figure A-26: PHKG box plot and temperature breakdown, Week 5.

	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	22.1	23.2	25.8	22.9	21.1
Max	24.9	24.4	27.5	24.5	22.8
Min	20.8	22.7	25.0	21.6	20.6
Third Quartile	23.9	24.0	27.1	23.9	22.1
Median	23.2	23.5	26.5	23.4	21.7

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

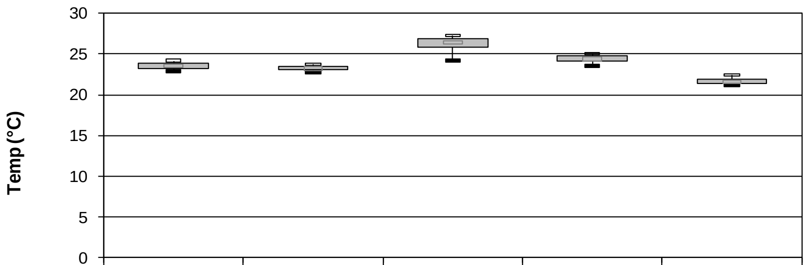
Figure A-27: PHKG box plot and temperature breakdown, Week 6.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.8	23.4	25.6	23.7	21.3
Max	24.8	24.4	27.9	24.9	22.7
Min	23.1	22.8	23.0	23.1	20.3
Third Quartile	24.4	24.0	26.7	24.3	22.0
Median	24.2	23.8	26.1	24.0	21.6

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

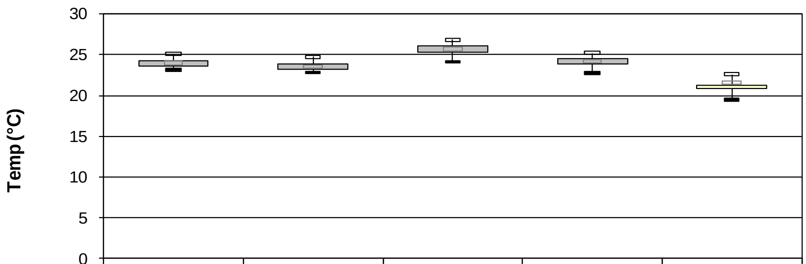
Figure A-28: PHKG box plot and temperature breakdown, Week 7.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.3	23.1	25.8	24.1	21.4
Max	24.2	23.7	27.3	25.1	22.4
Min	22.9	22.7	24.2	23.5	21.2
Third Quartile	23.9	23.5	26.8	24.8	21.8
Median	23.5	23.2	26.4	24.4	21.6

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

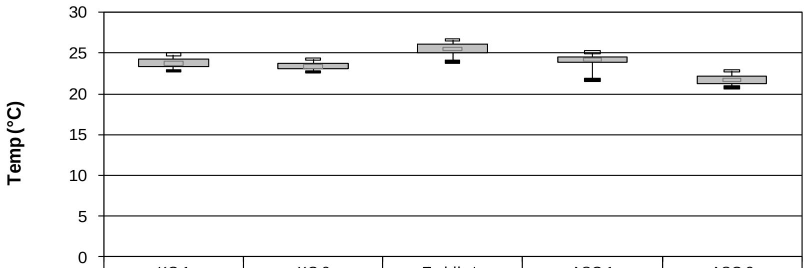
Figure A-29: PHKG box plot and temperature breakdown, Week 8.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.6	23.2	25.3	23.9	21.2
Max	25.1	24.7	26.8	25.2	22.6
Min	23.2	22.8	24.1	22.8	19.5
Third Quartile	24.3	23.9	26.0	24.6	20.9
Median	24.0	23.6	25.7	24.2	21.5

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

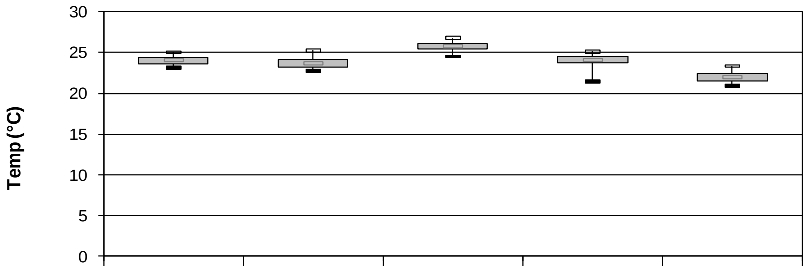
Figure A-30: PHKG box plot and temperature breakdown, Week 9.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.4	23.0	25.0	23.9	21.3
Max	24.8	24.3	26.6	25.1	22.8
Min	22.8	22.7	23.9	21.7	20.8
Third Quartile	24.2	23.7	26.1	24.5	22.1
Median	23.7	23.4	25.5	24.2	21.7

KG 1 KG 2 Toddler's ASG 1 ASG 2

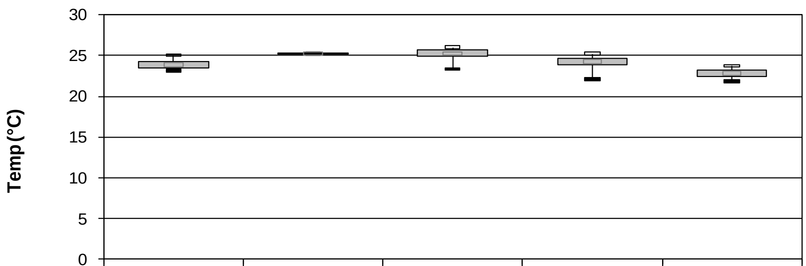
Figure A-31: PHKG box plot and temperature breakdown, Week 10.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.6	23.2	25.5	23.8	21.6
Max	25.1	25.3	26.8	25.1	23.4
Min	23.1	22.7	24.5	21.4	20.9
Third Quartile	24.3	24.1	26.1	24.5	22.4
Median	24.0	23.7	25.8	24.0	22.0

KG 1 KG 2 Toddler's ASG 1 ASG 2

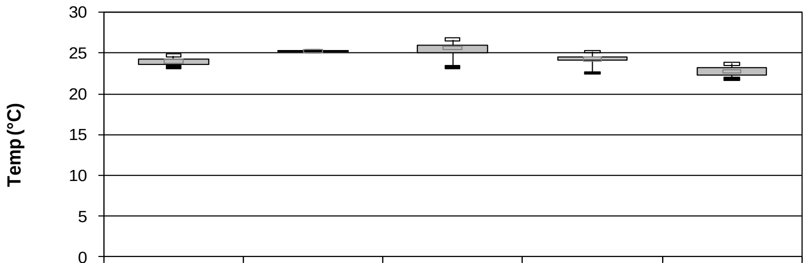
Figure A-32: PHKG box plot and temperature breakdown, Week 11.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.5	25.3	24.9	23.9	22.4
Max	25.1	25.3	26.0	25.2	23.7
Min	23.1	25.3	23.3	22.1	21.9
Third Quartile	24.2	25.3	25.7	24.6	23.2
Median	23.9	25.3	25.3	24.3	22.8

KG 1 KG 2 Toddler's ASG 1 ASG 2

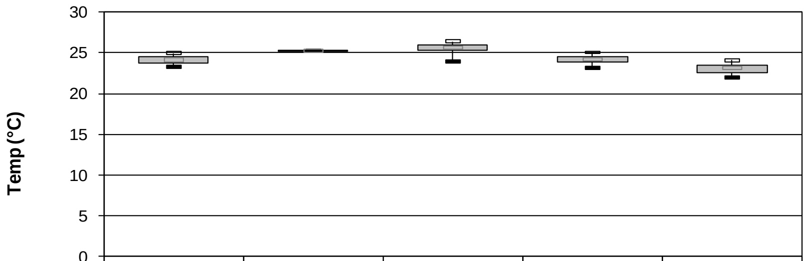
Figure A-33: PHKG box plot and temperature breakdown, Week 12.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.6	25.3	25.1	24.1	22.3
Max	24.7	25.3	26.7	25.2	23.7
Min	23.3	25.3	23.3	22.6	21.8
Third Quartile	24.2	25.3	25.9	24.5	23.2
Median	24.0	25.3	25.6	24.3	22.7

KG 1 KG 2 Toddler's ASG 1 ASG 2

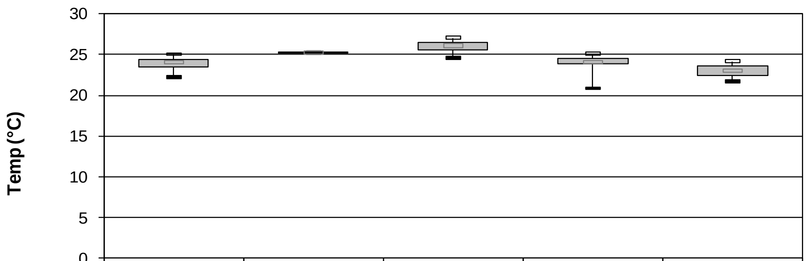
Figure A-34: PHKG box plot and temperature breakdown, Week 13.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.8	25.3	25.3	23.9	22.5
Max	25.0	25.3	26.4	25.1	24.1
Min	23.3	25.3	23.9	23.2	22.0
Third Quartile	24.5	25.3	26.0	24.5	23.5
Median	24.1	25.3	25.7	24.2	23.1

KG 1 KG 2 Toddler's ASG 1 ASG 2

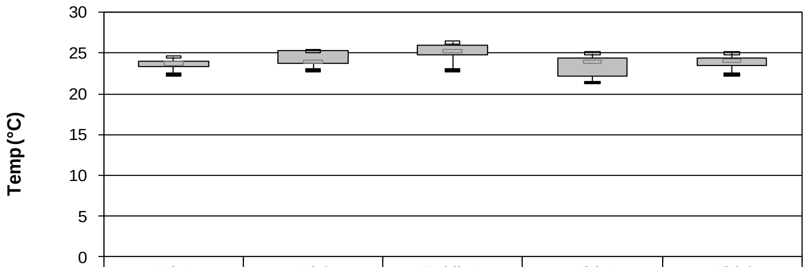
Figure A-35: PHKG box plot and temperature breakdown, Week 14.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.4	25.3	25.6	23.9	22.4
Max	25.0	25.3	27.1	25.1	24.2
Min	22.2	25.3	24.6	20.9	21.7
Third Quartile	24.3	25.3	26.5	24.5	23.5
Median	24.0	25.3	26.1	24.1	23.1

KG 1 KG 2 Toddler's ASG 1 ASG 2

Figure A-36: PHKG box plot and temperature breakdown, Week 15.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	23.3	23.7	24.7	22.1	23.5
Max	24.5	25.3	26.3	25.0	25.0
Min	22.3	22.9	22.8	21.4	22.4
Third Quartile	24.0	25.3	26.0	24.4	24.4
Median	23.7	24.0	25.3	24.0	24.1

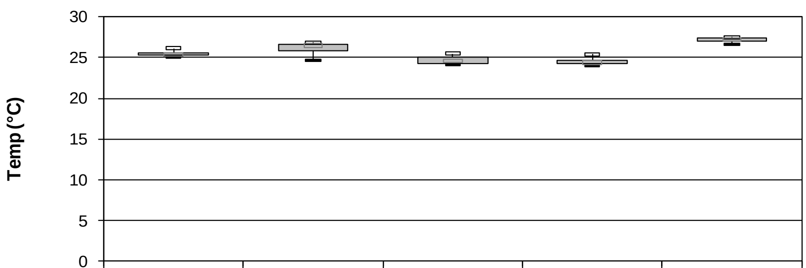
KG 1 KG 2 Toddler's ASG 1 ASG 2

Figure A-37: PHKG box plot and temperature breakdown, Week 16.

	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	24.6	23.8	22.6	22.3	24.7
Max	26.0	25.2	24.2	23.4	26.2
Min	24.3	23.0	22.2	21.8	23.9
Third Quartile	25.6	24.8	23.5	22.7	25.5
Median	24.9	24.4	23.1	22.5	25.1

KG 1 KG 2 Toddler's ASG 1 ASG 2

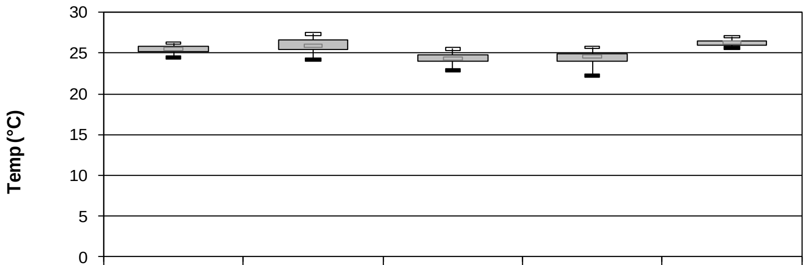
Figure A-38: PHKG box plot and temperature breakdown, Week 17.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	25.3	25.8	24.3	24.2	26.9
Max	26.1	26.8	25.5	25.4	27.5
Min	25.0	24.6	24.2	24.0	26.6
Third Quartile	25.6	26.6	25.0	24.6	27.4
Median	25.4	26.5	24.6	24.4	27.2

KG 1 KG 2 Toddler's ASG 1 ASG 2

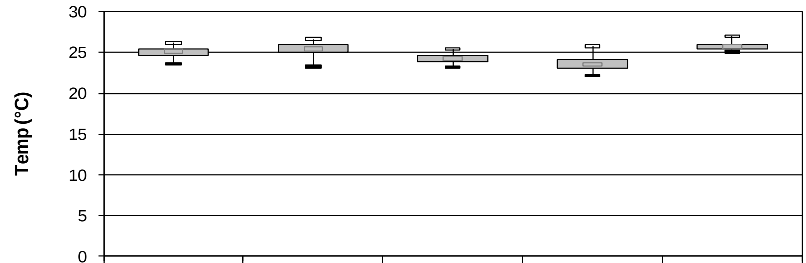
Figure A-39: PHKG box plot and temperature breakdown, Week 18.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	25.2	25.5	24.0	24.0	26.0
Max	26.2	27.3	25.5	25.7	27.0
Min	24.5	24.2	22.9	22.2	25.7
Third Quartile	25.8	26.6	24.8	25.0	26.5
Median	25.5	25.9	24.3	24.6	26.3

KG 1 KG 2 Toddler's ASG 1 ASG 2

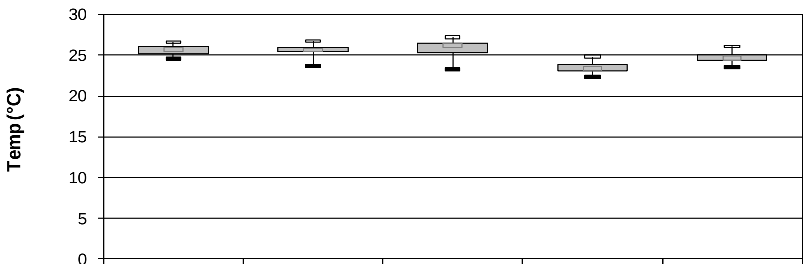
Figure A-40: PHKG box plot and temperature breakdown, Week 19.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	24.7	25.1	23.9	23.1	25.4
Max	26.2	26.7	25.4	25.8	27.0
Min	23.6	23.3	23.2	22.2	25.1
Third Quartile	25.5	25.9	24.6	24.2	26.0
Median	25.2	25.4	24.3	23.5	25.7

KG 1 KG 2 Toddler's ASG 1 ASG 2

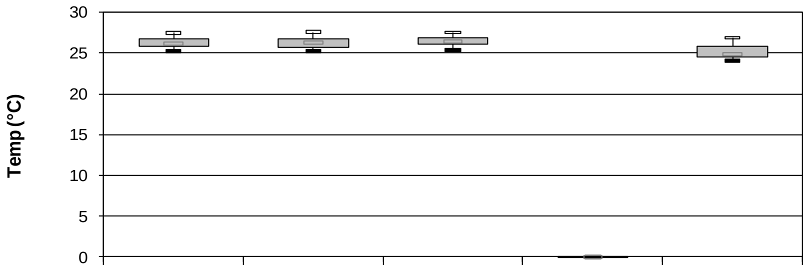
Figure A-41: PHKG box plot and temperature breakdown, Week 20.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	25.2	25.5	25.3	23.1	24.4
Max	26.6	26.7	27.2	24.8	26.1
Min	24.6	23.7	23.2	22.4	23.6
Third Quartile	26.0	25.9	26.5	23.9	25.0
Median	25.7	25.7	26.2	23.3	24.7

KG 1 KG 2 Toddler's ASG 1 ASG 2

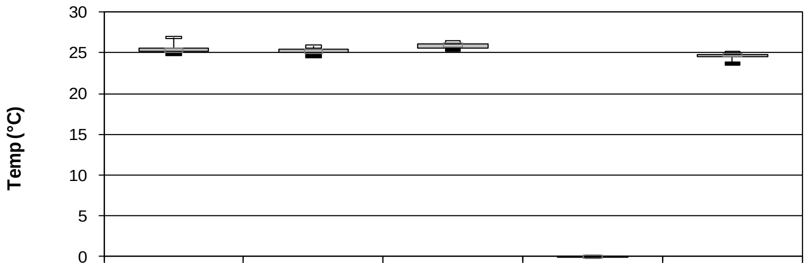
Figure A-42: PHKG box plot and temperature breakdown, Week 21.



	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	25.8	25.6	26.1	0.0	24.6
Max	27.5	27.6	27.5	0.0	26.9
Min	25.3	25.2	25.3	0.0	24.1
Third Quartile	26.8	26.7	26.9	0.0	25.9
Median	26.1	26.3	26.4	0.0	24.9

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

Figure A-43: PHKG box plot and temperature breakdown, Week 22.

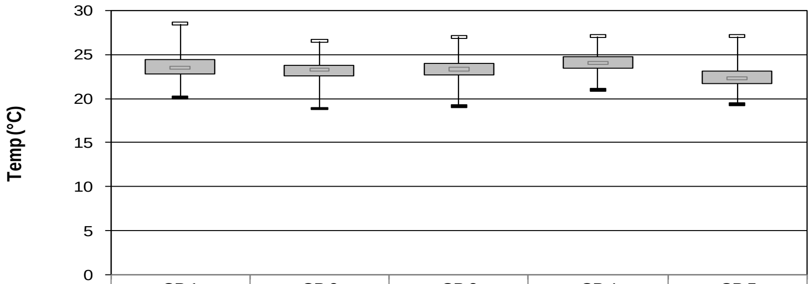


	KG 1	KG 2	Toddler's	ASG 1	ASG 2
First Quartile	25.2	25.0	25.6	0.0	24.5
Max	26.9	25.8	26.3	0.0	25.0
Min	24.8	24.6	25.4	0.0	23.6
Third Quartile	25.6	25.4	26.1	0.0	24.8
Median	25.3	25.2	26.0	0.0	24.7

KG 1 **KG 2** **Toddler's** **ASG 1** **ASG 2**

Figure A-44: PHKG box plot and temperature breakdown, Week 23.

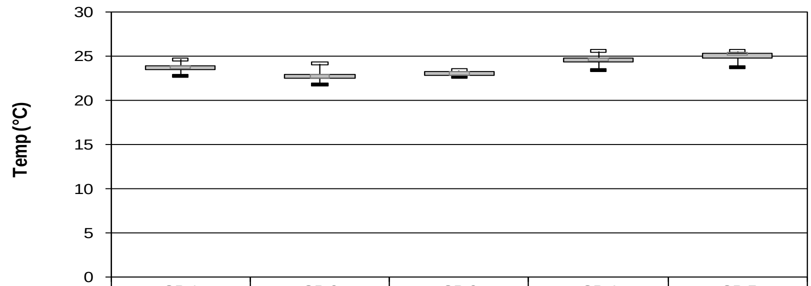
8.3.2. SKG Summary & Weekly Box Plot Graphs



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.8	22.6	22.7	23.4	21.7
Max	28.5	26.5	27.0	27.1	27.1
Min	20.1	18.9	19.2	21.0	19.4
Third Quartile	24.5	23.8	24.0	24.8	23.1
Median	23.5	23.3	23.3	24.1	22.3

GR 1 **GR 2** **GR 3** **GR 4** **GR 7**

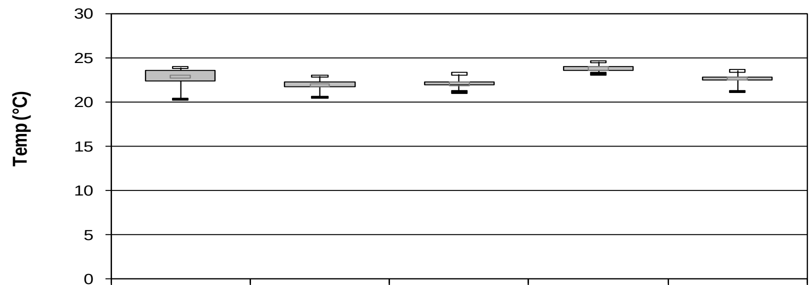
Figure A-45: SKG classroom box plot and temperature breakdown for the study period.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	23.4	22.5	22.9	24.4	24.8
Max	24.6	24.2	23.4	25.6	25.6
Min	22.7	21.8	22.7	23.4	23.7
Third Quartile	24.0	23.0	23.3	24.8	25.3
Median	23.8	22.7	23.0	24.6	25.3

GR 1 **GR 2** **GR 3** **GR 4** **GR 7**

Figure A-46: SKG box plot and temperature breakdown, Week 1.



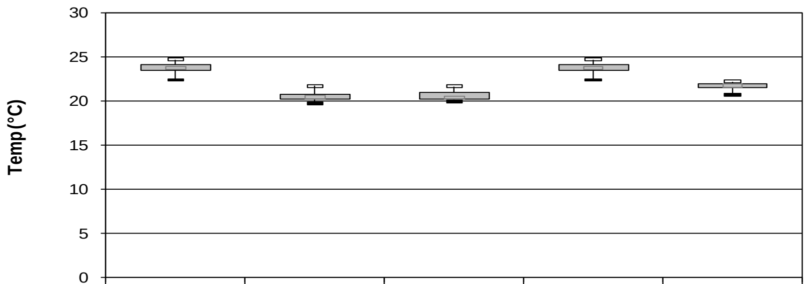
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.3	21.7	22.0	23.6	22.5
Max	23.9	22.9	23.2	24.6	23.6
Min	20.3	20.5	21.1	23.2	21.2
Third Quartile	23.6	22.3	22.3	24.1	22.8
Median	22.9	21.9	22.1	23.8	22.7

GR 1 **GR 2** **GR 3** **GR 4** **GR 7**

Figure A-47: SKG box plot and temperature breakdown, Week 2.

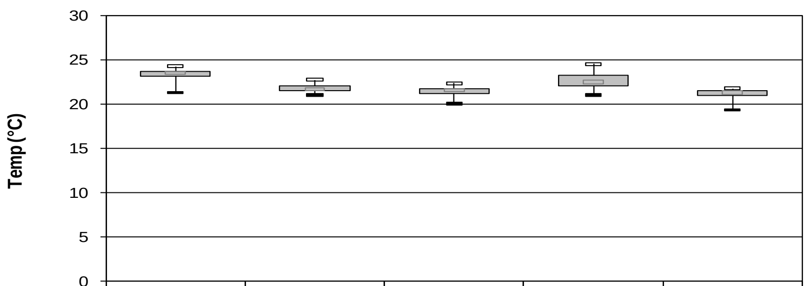
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	23.3	19.8	19.9	21.6	20.2
Max	24.2	21.4	21.8	23.9	22.3
Min	22.5	18.9	19.2	21.3	19.7
Third Quartile	24.2	21.4	21.7	23.6	22.2
Median	23.5	20.1	20.0	22.1	21.0
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-48: SKG box plot and temperature breakdown, Week 3.



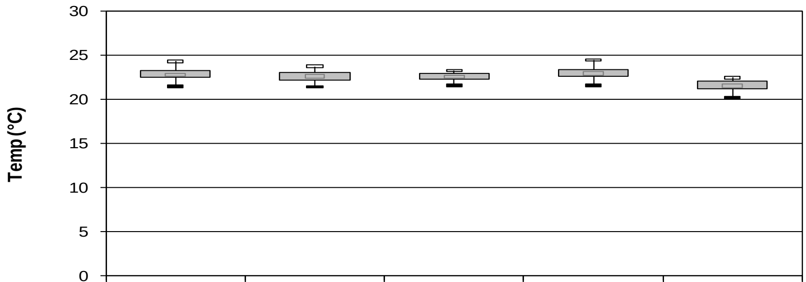
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	23.5	20.2	20.3	23.5	21.5
Max	24.7	21.7	21.7	24.7	22.2
Min	22.4	19.7	20.0	22.4	20.7
Third Quartile	24.2	20.7	21.0	24.2	21.9
Median	23.8	20.4	20.4	23.8	21.7
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-49: SKG box plot and temperature breakdown, Week 4.



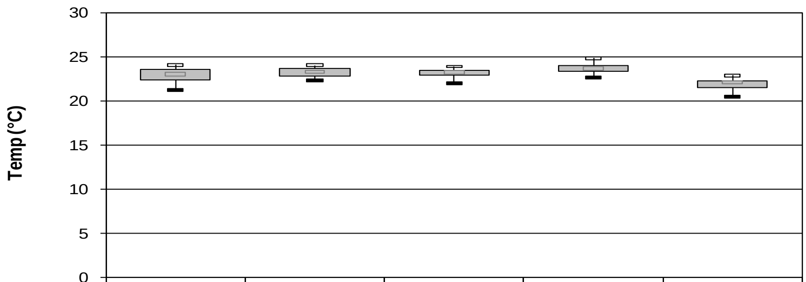
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	23.1	21.5	21.2	22.1	21.0
Max	24.3	22.8	22.4	24.6	21.8
Min	21.3	21.0	20.1	21.0	19.4
Third Quartile	23.7	22.1	21.8	23.3	21.5
Median	23.5	21.7	21.6	22.5	21.3
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-50: SKG box plot and temperature breakdown, Week 5.



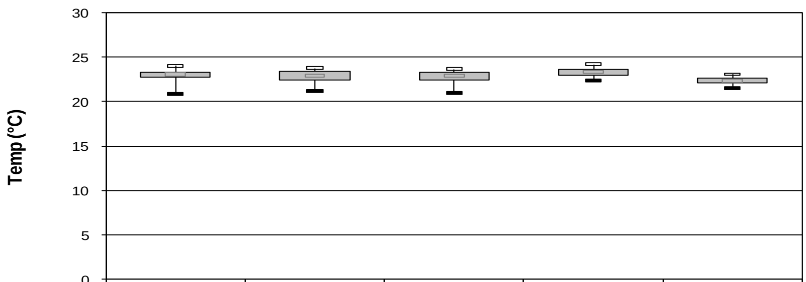
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.5	22.2	22.3	22.6	21.2
Max	24.3	23.7	23.3	24.5	22.5
Min	21.5	21.4	21.6	21.6	20.2
Third Quartile	23.3	23.1	22.9	23.4	22.1
Median	22.8	22.6	22.6	22.9	21.5
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-51: SKG box plot and temperature breakdown, Week 6.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.4	22.8	22.9	23.4	21.5
Max	24.1	24.1	23.9	24.8	22.9
Min	21.3	22.4	22.0	22.7	20.5
Third Quartile	23.6	23.7	23.5	24.1	22.3
Median	23.1	23.3	23.3	23.7	22.1
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-52: SKG box plot and temperature breakdown, Week 7.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.8	22.4	22.5	23.0	22.1
Max	24.0	23.7	23.7	24.2	23.1
Min	20.9	21.2	21.0	22.4	21.5
Third Quartile	23.3	23.4	23.3	23.7	22.6
Median	23.1	22.9	22.9	23.3	22.3
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-53: SKG box plot and temperature breakdown, Week 8.

	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	23.0	23.0	22.9	23.6	22.0
Max	24.4	24.1	24.0	24.7	23.1
Min	20.5	22.3	22.3	22.9	21.5
Third Quartile	23.8	23.6	23.6	24.1	22.5
Median	23.4	23.4	23.4	23.8	22.2

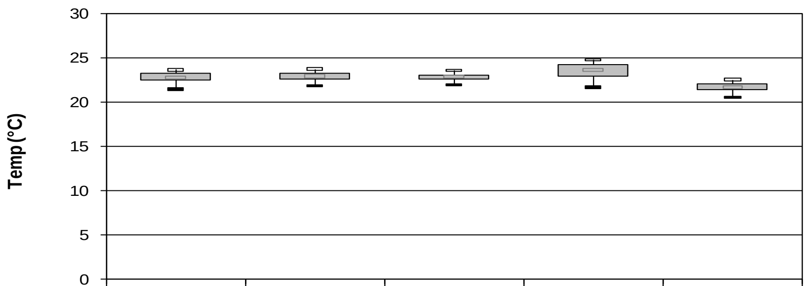
GR 1 **GR 2** **GR 3** **GR 4** **GR 7**

Figure A-54: SKG box plot and temperature breakdown, Week 9.

	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.2	22.7	22.7	23.1	21.8
Max	23.7	23.8	23.6	24.4	23.0
Min	20.9	22.1	21.7	21.9	20.6
Third Quartile	23.0	23.3	23.2	23.8	22.3
Median	22.7	22.9	23.0	23.5	22.1

GR 1 **GR 2** **GR 3** **GR 4** **GR 7**

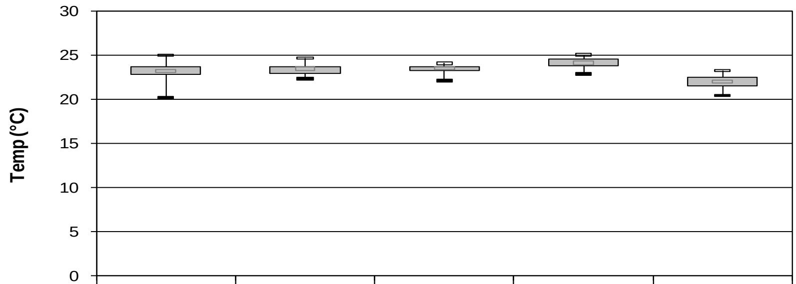
Figure A-55: SKG box plot and temperature breakdown, Week 10.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.5	22.7	22.7	22.9	21.4
Max	23.6	23.7	23.6	24.8	22.6
Min	21.5	21.8	22.0	21.7	20.6
Third Quartile	23.2	23.3	23.0	24.2	22.0
Median	22.8	23.0	22.9	23.6	21.7

GR 1 **GR 2** **GR 3** **GR 4** **GR 7**

Figure A-56: SKG box plot and temperature breakdown, Week 11.

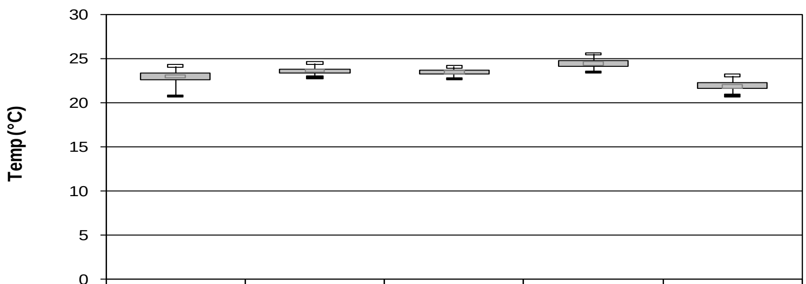


	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.8	22.9	23.3	23.8	21.6
Max	25.0	24.7	24.1	25.0	23.3
Min	20.1	22.4	22.1	22.9	20.4
Third Quartile	23.7	23.7	23.8	24.6	22.5
Median	23.2	23.5	23.6	24.1	22.0
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-57: SKG box plot and temperature breakdown, Week 12.

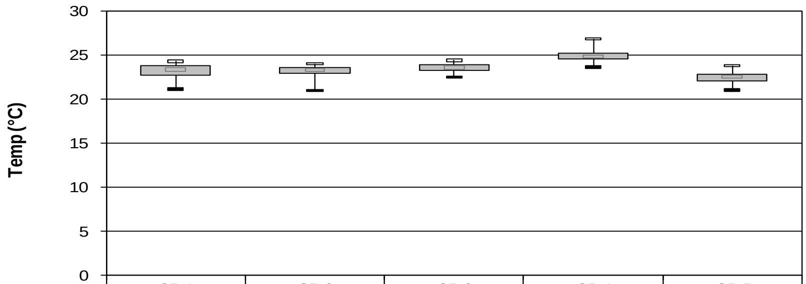
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.6	23.2	23.4	24.0	21.6
Max	24.5	24.1	24.1	25.3	22.8
Min	21.3	22.2	22.7	23.2	19.8
Third Quartile	23.5	23.8	23.8	24.7	22.2
Median	23.0	23.5	23.6	24.3	21.8
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-58: SKG box plot and temperature breakdown, Week 13.



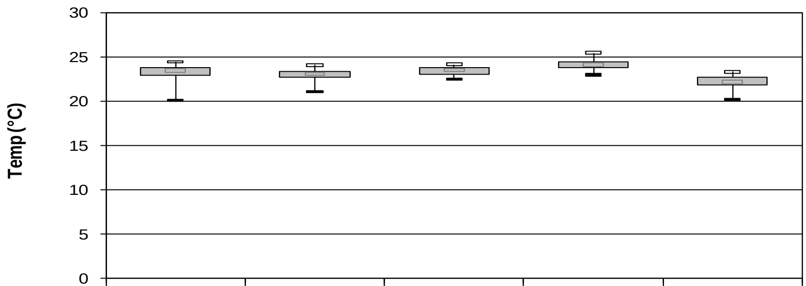
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.6	23.4	23.2	24.2	21.7
Max	24.2	24.5	24.1	25.6	23.1
Min	20.8	22.9	22.7	23.5	20.8
Third Quartile	23.4	23.8	23.7	24.8	22.3
Median	23.0	23.6	23.5	24.5	21.9
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-59: SKG box plot and temperature breakdown, Week 14.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.7	22.9	23.3	24.6	22.1
Max	24.3	24.0	24.4	26.9	23.8
Min	21.2	21.0	22.5	23.7	21.0
Third Quartile	23.8	23.6	23.9	25.2	22.8
Median	23.4	23.3	23.6	24.9	22.6
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-60: SKG box plot and temperature breakdown, Week 15.

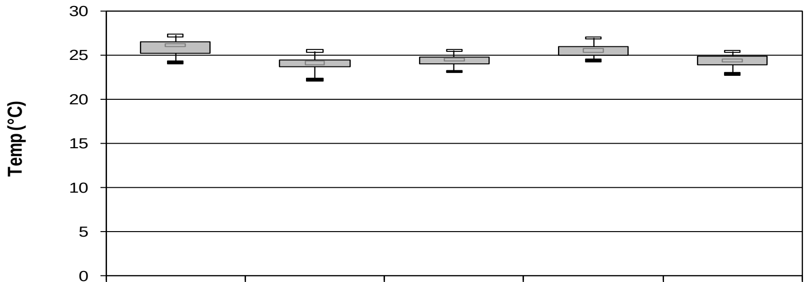


	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	22.9	22.8	23.0	23.9	21.8
Max	24.4	24.1	24.2	25.5	23.3
Min	20.1	21.1	22.5	23.0	20.2
Third Quartile	23.9	23.4	23.8	24.5	22.7
Median	23.5	23.1	23.5	24.1	22.2
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-61: SKG box plot and temperature breakdown, Week 16.

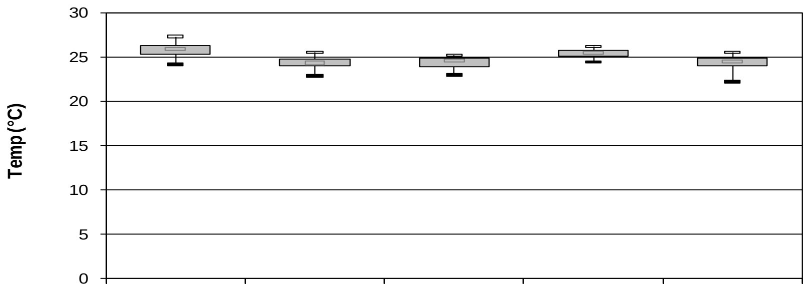
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	24.5	23.3	23.4	25.3	22.6
Max	26.7	24.9	25.0	26.6	24.8
Min	23.0	22.2	22.9	24.3	21.8
Third Quartile	25.7	24.2	24.3	26.2	24.2
Median	25.2	23.7	23.8	25.8	23.4
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-62: SKG box plot and temperature breakdown, Week 17.



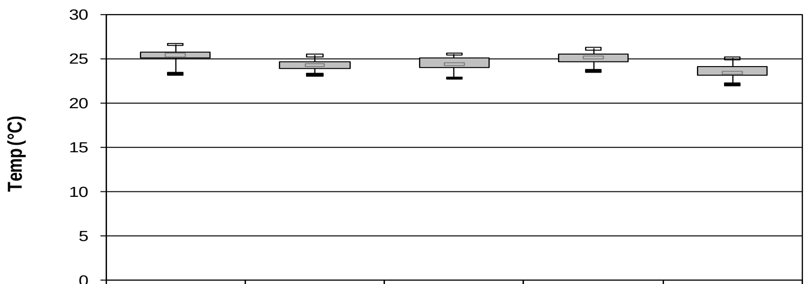
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	25.2	23.8	24.1	25.0	24.0
Max	27.3	25.5	25.6	27.0	25.4
Min	24.2	22.2	23.1	24.4	22.9
Third Quartile	26.6	24.4	24.8	26.0	24.9
Median	26.2	24.1	24.5	25.6	24.4
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-63: SKG box plot and temperature breakdown, Week 18.



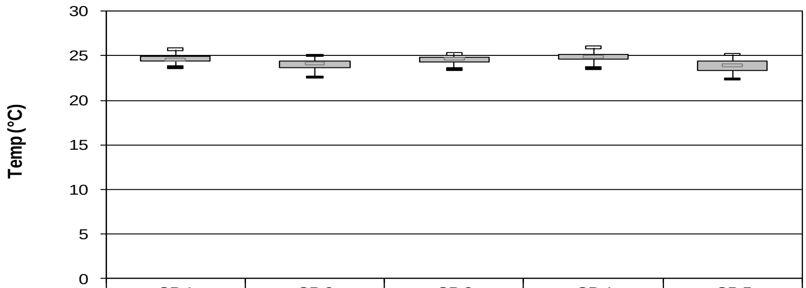
	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	25.3	24.0	23.9	25.2	24.0
Max	27.3	25.5	25.2	26.2	25.6
Min	24.2	22.9	23.0	24.5	22.2
Third Quartile	26.3	24.8	24.9	25.8	24.9
Median	25.9	24.3	24.6	25.5	24.5
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

Figure A-64: SKG box plot and temperature breakdown, Week 19.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	25.1	23.9	24.1	24.7	23.1
Max	26.7	25.4	25.6	26.2	25.1
Min	23.3	23.2	22.8	23.6	22.2
Third Quartile	25.8	24.7	25.1	25.5	24.1
Median	25.4	24.3	24.4	25.2	23.5
	GR 1	**GR 2**	**GR 3**	**GR 4**	**GR 7**

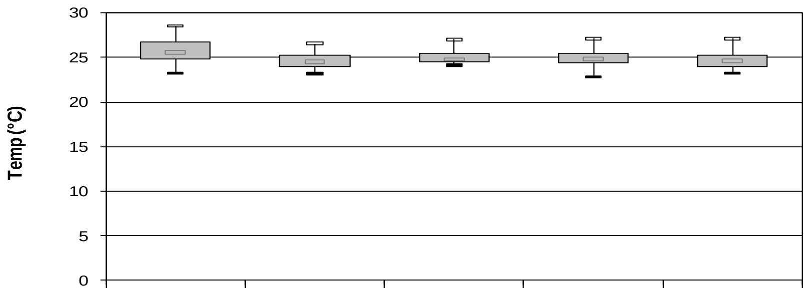
Figure A-65: SKG box plot and temperature breakdown, Week 20.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	24.4	23.7	24.2	24.6	23.3
Max	25.7	25.0	25.2	25.9	25.1
Min	23.7	22.6	23.5	23.6	22.4
Third Quartile	24.9	24.4	24.9	25.1	24.4
Median	24.6	24.1	24.7	24.9	23.9

GR 1 GR 2 GR 3 GR 4 GR 7

Figure A-66: SKG box plot and temperature breakdown, Week 21.



	GR 1	GR 2	GR 3	GR 4	GR 7
First Quartile	24.9	23.9	24.5	24.4	24.0
Max	28.5	26.5	27.0	27.1	27.1
Min	23.2	23.1	24.1	22.8	23.2
Third Quartile	26.7	25.3	25.4	25.5	25.3
Median	25.6	24.5	24.8	24.8	24.6

GR 1 GR 2 GR 3 GR 4 GR 7

Figure A-67: SKG box plot and temperature breakdown, Week 22.

8.4. Assumptions for Energy Analysis Calculations

The measured overall average indoor temperature for both kindergartens was taken for the months of January to May, and December. The mean indoor temperature was assumed to be 22°C for the other months. 22°C was the indoor temperature used for the architect's initial heating and energy demand calculations.

Table A-5: Indoor temperatures for calculations.

Month	PHKG [°C]	SKG [°C]
January	22.9	22.8
February	24.4	23.2
March	24.4	24.0
April	25.3	24.0
May	26.7	25.0
June	22.0	22.0
July	22.0	22.0
August	22.0	22.0
September	22.0	22.0
October	22.0	22.0
November	22.0	22.0
December	22.0	22.6

A test reference climate is usually used for the exterior conditions. However, the available actual average monthly temperatures for the six month study period were used instead of the respective standard values.

DHW consumption was calculated assuming that each person washed their hands 3 times per day each time for 1 minute, and two litres per minute of water was used. Dishwashing and laundry were not included as it is standard practice to use water from the cold water supply for both appliances. It was assumed that lighting was used all year round and the electricity consumptions were converted into a monthly mean for a combined lighting and equipment load, Table A-6.

Table A-6: Assumed internal conditions.

	PHKG	SKG
Internal Heat Gain, People [W/m^2]	3.4	2.9
Internal Heat Gain, Lighting & Equipment [W/m^2]	3.6	3.5
Air Change Rate [h^{-1}]	0.9	0.7
DHW Demand [l/day]	1,410.0	990.0

Carbon dioxide emissions were calculated using the conversion factors from DIN EN 15603:2008.

8.4.1. Energy Analysis, Calculated Values

Overall, the total costs of the PHKG are estimated to be 20% lower than the SKG due to the dramatic decrease in the annual heating demand. The SKG's HWB_{GFA} is deduced to be five times greater than the PHKG despite the fact that the gross area is 20% larger. Loads are slightly higher for DHW as well as for lighting and equipment. However, the PHKG population is almost double that of the SKG and the increase in DHW load is not in proportion with the difference in population. The calculated lighting and equipment loads are also higher due to the difference in size and the PHKG's longer hours of operation. Similar to the DHW load, the increase in the amount of energy required for lighting and equipment is not reflective of the longer hours of operation and the larger kindergarten size. Table A-7 summarizes the energy breakdown. The costs in Table A-7 are the total costs from the energy bills.

Table A-7: Energy summary.

	Heating		Domestic Hot Water		Lighting & Equipment		Total Energy	
	PHKG	SKG	PHKG	SKG	PHKG	SKG	PHKG	SKG
HWB_{GFA} [kWh/m²·GFA]	21.5	123.5	27.7	23.3	-	-	-	-
Annual Energy Demand [kWh/m²·GFA]	39.4	138.8	25.3	33.7	31. 8	30.6	78.39	203.22
Costs [€/a]	3,678.75	8,112.72	2,629.82	2,482.5	6,187.06	4,964.42	12,495.63	15,559.68
CO_2 Emissions [tonnes/a]	18.5	45.5	12.3	12.7	25.5	20.4	56.7	78.7
Primary Energy Content [kWh/m²·GFA]	72.6	209.8	50.5	59.8	104.9	101.1	228.0	370.8

Figure A-68 shows that the heating season has been shortened by two months in the PHKG. Even in the coldest months, the heating demand is a quarter that of the SKG.

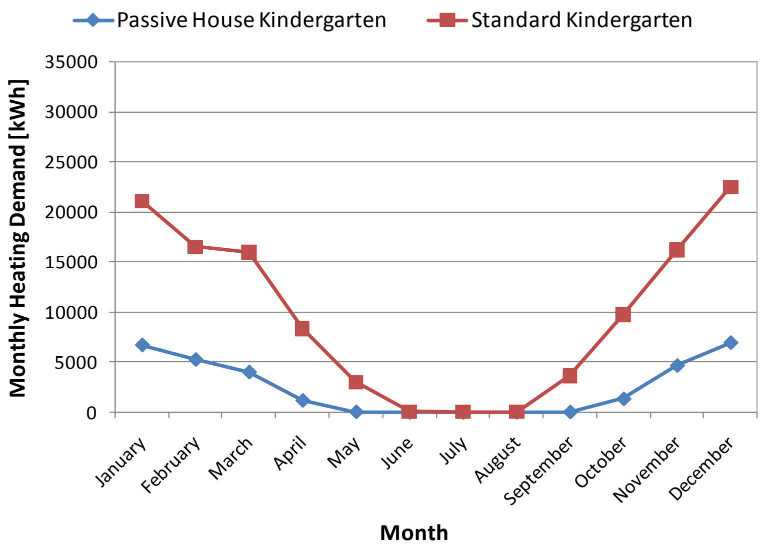


Figure A-68: Calculated annual heating demand, monthly analysis.

As part of the DHW demand in the PHKG is carried by the solar collectors, there is very little change in the flatness of the slope from May until August; whereas the SKG carries a summer heating load. The annual heating energy requirement combines the DHW and system losses with the annual heating demand as per Formula (7). Figure A-69 includes the energy required for DHW in the monthly heating energy demand.

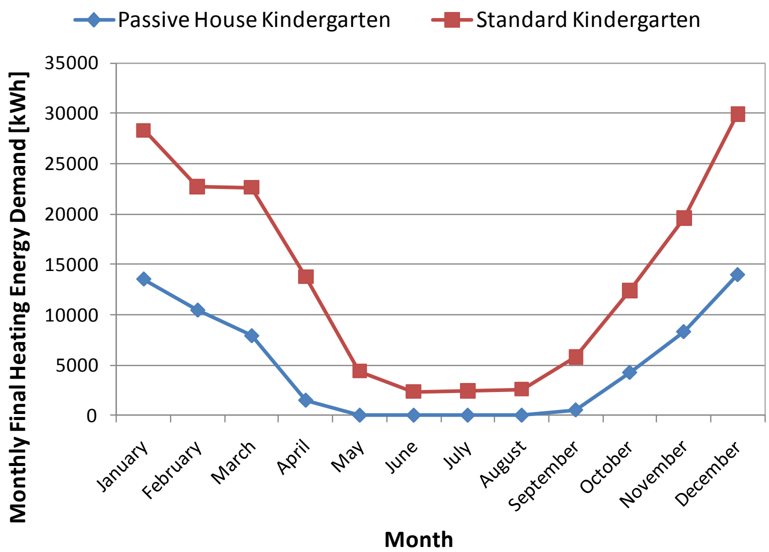


Figure A-69: Annual final energy demand for heating & DHW, monthly analysis.

The calculated annual heating demand per unit area, HWB_{GFA}, for the PHKG by the architects was 13.3 kWh/m^2·a (Architekturbüro Reinberg ZT GmbH, 2004), whereas the calculated HWB_{GFA} from the drawings and specifications is 21.5 kWh/m^2·a. When compared to the Passive House calculations, the heating energy demand is 30% higher when using the actual average indoor temperatures. By substituting 22°C as the indoor temperature in the calculations using the Excel tool from Riccabona, the annual heating demand for the PHKG falls to 18 kWh/m^2·a.The main difference between the calculation procedures is that the overall building volume in the drawings is approximately 1.5 times larger due to higher room heights leading to a much larger building volume than the original architect's calculations using the Passive House Planning Package (PHPP), and that the recorded indoor temperatures are higher than the design values.

The annual PHKG values are computationally divided using a factor based on the proportionality of calculated values using the nine month recorded values, using Formula (8):

Extrapolated PHKG annual energy use =

9 month consumption(12 month calculated energy use/9 month calculated energy use) (8)*

See Table A-8. The factor is multiplied by the monthly proportion of the calculated total energy use in column 3 resulting in the extrapolated PHKG values in column 4. Column 5 gives the PHKG total energy use per unit area, and the recorded values of the SKG are displayed similarly in columns 6 & 7.

Table A-8: Actual heating energy use for space heating & DHW.

Month	Calculated PHKG Heating & DHW Use	Proportion	Extrapolated PHKG Heating & DHW Use	Extrapolated PHKG Heating & DHW Use/m²	Actual SKG Heating & DHW	Actual SKG Heating & DHW Use/m²
January	13,520.1	0.22	24,361.4	18.8	29,000.0	26.9
February	10,436.4	0.17	18,805.1	14.5	25,000.0	23.1
March	7,889.9	0.13	14,216.6	11.0	24,000.0	22.2
April	1,485.9	0.02	2,677.3	2.1	19,000.0	17.6
May	0.0	0.00	0.0	0.0	9,000.0	8.3
June	0.0	0.00	0.0	0.0	4,000.0	3.7
July	0.0	0.00	0.0	0.0	3,000.0	2.8
August	0.0	0.00	0.0	0.0	3,000.0	2.8
September	527.0	0.01	949.6	0.7	10,000.0	9.3
October	4,247.8	0.07	7,654.0	5.9	20,000.0	18.5
November	8,296.6	0.14	14,949.3	11.5	21,000.0	19.4
December	13,955.5	0.23	25,146.0	19.4	26,000.0	24.1
	60,359.2	**1.00**	**108,759.3**	**83.8**	**193,000.0**	**178.7**

The electricity use in both kindergartens over the nine month period is outlined in Table A-9. Electricity use is 20.6% higher in the PHKG overall when compared on a kWh/ m^2 basis.

Table A-9: Actual electricity use, 9 month period.

	SKG		PHKG	
2008	Electricity Use [kWh]	Electricity Use [kWh/m^2]	Electricity Use [kWh]	Electricity Use [kWh/m^2]
January	3,139.0	3.0	4,134.0	3.5
February	3,084.0	3.0	3,940.0	3.4
March	2,635.0	2.5	3,696.0	3.1
April	2,841.0	2.7	3,774.0	3.2
May	2,172.0	2.1	3,074.0	2.6
June	2,056.0	2.0	3,092.0	2.6
July	2,083.0	2.0	2,767.0	2.4
August	2,014.0	1.9	2,533.0	2.2
September	2,615.0	2.5	3,887.0	3.3
	22,639.0	**21.8**	**30,897.0**	**26.3**

Table A-10 shows the annual electricity use using calculated values for deriving the monthly values for the whole year for the PHKG using the nine months of electricity bills. Electricity use is 9.3% higher in the PHKG overall when compared on a kWh/ m^2 basis.

Table A-10: Actual electricity use, annual.

Month	Calculated PHKG Electricity Use	Proportion	Extrapolated PHKG Electricity Use	Extrapolated PHKG Electricity Use/m^2	Actual SKG Electricity Use	Actual SKG Electricity Use/m^2
January	3,503.2	0.08	4,134.0	2.7	3,139.0	2.9
February	3,164.2	0.08	3,940.0	2.4	3,084.0	2.9
March	3,503.2	0.08	3,696.0	2.7	2,635.0	2.4
April	3,390.2	0.08	3,774.0	2.6	2,841.0	2.6
May	3,503.2	0.08	3,074.0	2.7	2,172.0	2.0
June	3,390.2	0.08	3,092.0	2.6	2,056.0	1.9
July	3,503.2	0.08	2,767.0	2.7	2,083.0	1.9
August	3,503.2	0.08	2,533.0	2.7	2,014.0	1.9
September	3,390.2	0.08	3,887.0	2.6	2,615.0	2.4
October	3,503.2	0.08	3,508.5	2.7	3,091.0	2.9
November	3,390.2	0.08	3,395.3	2.6	3,058.0	2.8
December	3,503.2	0.08	3,508.5	2.7	2,691.0	2.5
	41,247.1	**1.00**	**41,309.3**	**31.8**	**31,479.0**	**29.1**