SMART SCHOOL BUILDINGS

UPGRADING THE LEVEL OF ENERGY EFFICIENCY OF SCHOOL BUILDINGS IN THE NETHERLANDS

STACEY KUIPERS

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PREFACE

This master thesis is the result of my graduation research as the final part of my master Construction Management and Engineering at the University of Technology in Eindhoven. This graduation research is carried out for and in collaboration with HEVO. I want to thank HEVO for giving me the opportunity to graduate within their company. Especially, I want to thank Gerhard Jacobs for the guidance during my graduation research.

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Stacey Kuipers
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SUMMARY

Due to environmental problems, such as climate change, ozone layer depletion and air pollution, the European Union has introduced various Energy Policies. The Energy Performance of Buildings Directive (EPBD) is one of them, which sets requirements for Nearly Zero-Energy Buildings (NZEB). These requirements focus on four building features, dwellings, utility buildings, educational buildings and healthcare buildings. These NZEB requirements sets standards for the energy demand, the primary fossil energy consumption and the share of renewable energy. The energy demand stands for the energy used only for heating and cooling a building. The primary fossil energy consumption means the energy used for heating and cooling, but also for ventilation and hot water preparation. In the primary fossil energy consumption also system losses are taken into account. Based on the new requirements, all new buildings must meet the NZEB requirements after the end of 2020. In addition, the abolishing of net metering scheme, which might be implemented after 2023, will enhance the role of energy storage systems.

The focus of this research is on primary and secondary school buildings. The quality of school buildings in the Netherlands varies, just like the financial resources on local and regional level. There is a research gap identified from literature review that the preferences of energy efficiency technologies by school building users are mainly not taken into account during construction or renovation.

The aim of this research is to investigate which energy efficient technologies are technically applicable in school buildings and what are the school building user preferences for these technologies.

In the literature study, several energy efficient technologies are described. These are technologies for heating/cooling, ventilation, renewable energy, energy storage and building automation. To meet the NZEB requirements, the technologies must (1) reduce the energy consumption, (2) improve the level of energy efficiency and (3) increase the share of renewable energy. For the abolishment of the net metering restrictions, technologies for energy storage are also important.

The technologies which can be technically applied in school buildings to reduce the energy consumption are cogeneration and trigeneration, balanced heat recovery systems, earth-air tube ventilation and three building automation technologies, namely automatic lighting, automatic sun blinds and automatic daylight control. These seven technologies are also proved to be energy efficient. Other energy efficient technologies which can be technically applied in school buildings are low temperature heating, high temperature cooling, radiant wall and ceiling panels and thermally activated building system (TABS). TABS is not applicable in existing buildings, according to the literature. To increase the share of renewable energy, technologies such as horizontal and vertical ground source heat pumps, groundwater heat pumps, air to air and air to water heat pumps, heat pump water heaters, solar water heaters, PV panels and PV glazing can be technically applied. These nine technologies are also energy efficient because of the use of a natural energy source. To capture the generated energy, three energy storage systems can be used, namely thermal energy storage, battery energy storage and smart grid.

After the literature study, the energy consumption pattern of ten school buildings is described. These ten school buildings are both primary and secondary school buildings. The energy consumption pattern show that the school buildings mainly consume the energy between 7 o'clock in the morning and 8 o'clock in the evening. Influencing factors on the energy consumption pattern are the outdoor temperature, the amount of pupils, the application of solar panels and the implementation of a cooling system.

Thereafter, a panel data regression analysis is performed to analyze the energy consumption of school buildings. The most influencing factors on the energy consumption of school buildings are the education time and the EPC value. As expected, during vacation time less energy is consumed and during education time more energy is consumed. During the winter, the most energy is consumed and the least energy is consumed during spring. On Mondays and Tuesdays the most energy is consumed and as expected the least energy is consumed on Sundays. Also the results prove that the higher the area (m^2) per pupil, the higher the energy consumption. A high efficiency boiler combined with a ground/air heat pump and a balanced heat recovery system appears to have the lowest energy consumption. An air handling unit and natural ventilation consumes the most energy. For the EPC value and the amount of solar panels, contradictory results are shown in the estimated model. It is assumed that this contradiction is caused by one of the school buildings with inexplicable energy use. It is important to keep in mind that the analysis includes a small sample size of only ten school buildings.

Finally, the school building user preferences for the energy efficient technologies are investigated. To explore the user preferences, a discrete choice experiment is conducted with the aid of questionnaires. The respondents are teachers of primary and secondary schools and pupils of secondary schools. 376 valid questionnaires are completed by the respondents. The questionnaire consists of three parts, a personal characteristics part, an environmental behavior part and the part with hypothetical choice situations. In the environmental part, the results show that the teachers are more likely to be environmental friendly and energy conscious in comparison with pupils. In the hypothetical choice situations, conventional and energy efficient technologies for heating, ventilation, lighting and sun blinds are included. For each choice set, two classrooms with combined technologies sets and a “none of both” option are presented to respondents. They are requested to choose the most preferred one among these three options. These technologies are presented with their advantages and disadvantages. For example for PV panels a disadvantage can be that classrooms might be less warm in comparison with no PV panels. Respondents might make their choices based on the room temperature instead of the technology. This must be noted while interpreting the results.

376 valid respondents including both teachers and pupils were used for model estimation. Each respondent answered 12 choice sets. Mixed logit models have been applied to asses differences in preferences between respondents. The discrete choice experiment results proved that the preferences of the respondents are widely spread and show significant variation. The ventilation system is for both pupils and teachers the most influencing factor on the choice of technologies in a class room. The energy efficient ventilation system is chosen above the conventional system. This also account for the heating system. For lighting system and sun blinds, both the pupil and teachers are likely to choose the conventional system above the energy efficient system. For PV panels, the teachers slightly prefer to have PV panels while pupils prefer not having PV panels, probably because the linked disadvantage of less comfortable classrooms. Teachers are more likely to choose the energy efficient technologies in comparison with pupils. There can be concluded that teachers are more energy conscious in comparison with pupils.

SAMENVATTING

Door verschillende milieuproblemen, zoals klimaatverandering, aantasting van de ozonlaag en luchtvervuiling, heeft de Europese Unie haar energiebeleid aangescherpt. De richtlijn energieprestatie van gebouwen (EPBD) stelt eisen aan bijna energieneutrale gebouwen (BENG). Deze eisen zijn gericht op vier typen gebouwen, namelijk woningen, utiliteitsgebouwen, onderwijsgebouwen en zorggebouwen. Deze BENG eisen stellen normen voor energiebehoefte, primair fossiel energiegebruik en het aandeel hernieuwbare energie. De energiebehoefte staat voor de energie die alleen verbruikt wordt voor de verwarming en koeling van een gebouw. Het primair fossiel energiegebruik omvat de energie die wordt gebruikt voor verwarming en koeling, maar ook voor ventilatie en warm water. In het primair fossiel energiegebruik worden ook systeemverliezen meegenomen. Alle nieuw te bouwen gebouwen moeten na 2020 voldoen aan de BENG eisen. Daarnaast heeft de salderingsregeling ook invloed op de energievoorziening van gebouwen. Met de salderingsregeling kan de overtollige energie teruggestuurd en verrekend worden met de netbeheerder. Deze regeling zal na 2023 in Nederland verdwijnen. Daarom zal het opslaan van energie belangrijker worden.

Dit onderzoek richt zich op basisscholen en middelbare scholen. De kwaliteit van de schoolgebouwen in Nederland varieert, net als de financiële middelen die op lokaal en regionaal niveau beschikbaar zijn. Op basis van een literatuurstudie blijkt er weinig onderzoek gedaan te zijn naar energie-efficiënte schoolgebouwen en daarnaast worden de meningen van de gebruikers van deze gebouwen vaak niet meegenomen bij het realiseren of renoveren van schoolgebouwen.

Het doel van dit onderzoek is in kaart te brengen welke energie-efficiënte technologieën technisch toepasbaar zijn in schoolgebouwen en wat de voorkeuren van de gebruikers zijn met betrekking tot deze technologieën.

In de literatuurstudie worden verschillende energie-efficiënte technologieën beschreven. Dit zijn technologieën voor verwarming / koeling, ventilatie, hernieuwbare energie, energie-opslag en gebouwautomatisering. Om aan de BENG norm te voldoen, moeten de technologieën (1) het energieverbruik verminderen, (2) het niveau van energie-efficiëntie verbeteren en (3) het aandeel hernieuwbare energie verhogen. Door de toekomstige afschaffing van de salderingsregeling zijn technologieën voor energieopslag ook belangrijk.

De technologieën die technisch kunnen worden toegepast in schoolgebouwen om het energieverbruik te verminderen, zijn cogeneratie en trigeneratie, warmteterugwinning balansventilatie, grondbuisventilatie en drie technologieën voor gebouwautomatisering, namelijk automatische verlichting, automatische zonwering en automatische daglichtregeling. Deze zeven technologieën zijn ook energiezuinig. Andere energie-efficiënte technologieën die technisch kunnen worden toegepast in schoolgebouwen zijn lage temperatuur verwarming, hoge temperatuur koeling, klimaatwanden en -plafonds en betonkernactivering. Betonkernactivering kan niet worden toegepast in bestaande gebouwen. Om het aandeel hernieuwbare energie te vergroten, kunnen technologieën zoals horizontale en verticale grond-water warmtepompen, water-water warmtepompen, lucht-lucht en lucht-water warmtepompen, warmtepompboilers, zonneboilers, PV-panelen en PV-beglazing worden toegepast. Deze negen technologieën zijn ook energiezuinig vanwege het gebruik van een natuurlijke energiebron. Om de gegenereerde energie op te vangen, kunnen drie energieopslagsystemen worden gebruikt, namelijk thermische energieopslag, batterijen en smart grid.

Na de literatuurstudie wordt het energieverbruikspatroon van tien schoolgebouwen beschreven. Deze tien schoolgebouwen zijn zowel basis als middelbare schoolgebouwen. Het energieverbruikspatroon laat zien dat de schoolgebouwen tussen 7:00 uur en 20:00 uur de meeste energie verbruiken. Factoren die invloed hebben op het energieverbruikspatroon zijn de buitentemperatuur, het aantal leerlingen, de toepassing van zonnepanelen en de implementatie van een koelsysteem.

Daarna wordt een paneldata regressieanalyse uitgevoerd om het energieverbruik van schoolgebouwen te analyseren. De meest bepalende factoren voor het energieverbruik van schoolgebouwen zijn de schooltijden en de EPC-waarde. Zoals te verwachten, wordt tijdens de vakantie minder energie verbruikt en tijdens schooltijd wordt er meer energie verbruikt. In de winter wordt de meeste energie verbruikt en de minste energie wordt verbruikt in de lente. Op maandagen en dinsdagen wordt de meeste energie verbruikt en zoals verwacht wordt de minste energie verbruikt op zondag. Ook blijkt dat hoe groter de oppervlakte (m^2) per leerling is, hoe hoger het energieverbruik. Een HR-ketel in combinatie met een grond-/lucht-warmtepomp en een gebalanceerd warmteterugwinningssysteem blijken het laagste energieverbruik te hebben. Een luchtbehandelingsunit in combinatie met natuurlijke ventilatie verbruikt de meeste energie. Voor de EPC-waarde en het aantal zonnepanelen worden tegenstrijdigheden gevonden in het geschatte model. Deze tegenstrijdige resultaten worden waarschijnlijk veroorzaakt door een van de schoolgebouwen met een onverklaarbaar energieverbruik. Bovendien omvat deze analyse maar een kleine steekproef van slechts tien schoolgebouwen.

Ten slotte worden de voorkeuren van gebruikers van schoolgebouwen voor energie-efficiënte technologieën onderzocht. Om de gebruikersvoorkeuren aan te geven, wordt een discrete keuze-experiment uitgevoerd met behulp van enquêtes. De respondenten zijn docenten in het basis- en voortgezet onderwijs en leerlingen in het voortgezet onderwijs. In totaal zijn 376 bruikbare enquêtes ingevuld. De enquête bestaat uit drie delen, een deel met persoonlijke vragen, een deel over het gedrag ten opzichte van het milieu en een deel met hypothetische keuzevragen. In het tweede deel wordt aangetoond dat de docenten meer geneigd zijn om milieuvriendelijk en energiebewust te zijn dan de leerlingen. In de hypothetische keuzesituaties zijn energie-efficiënte technologieën voor verwarming, ventilatie, verlichting en zonwering inbegrepen. Deze technologieën worden in de vragenlijst vergeleken met het conventionele systeem. Daarnaast zijn ook zonnepanelen inbegrepen. Voor zonnepanelen kan worden gekozen tussen wel zonnepanelen of geen PV-panelen. Daarbij zijn de voor- en nadelen van de technologieën ook gepresenteerd. Voor zonnepanelen kan een nadeel bijvoorbeeld zijn dat klaslokalen minder warm zijn in vergelijking met geen zonnepanelen. Respondenten kunnen hierdoor hun keuzes maken op basis van de kamertemperatuur in plaats van de technologie. Dit moet worden meegenomen tijdens het interpreteren van de resultaten.

De 12 keuzes van 376 respondenten zijn gebruikt voor het schatten van discrete keuzemodellen. De resultaten van de mixed logit modellen tonen aan dat de voorkeuren van de respondenten erg verspreid zijn en veel variatie vertonen. Het ventilatiesysteem is voor zowel leerlingen als docenten de meest bepalende factor bij de keuze van technologieën voor een klaslokaal. Het energiezuinige ventilatiesysteem wordt gekozen boven het conventionele systeem. Dit geldt ook het verwarmingssysteem. Voor verlichting en zonwering kiezen, zowel de leerling als de docenten, het conventionele systeem boven het energiezuinige systeem. Met betrekking tot PV-panelen kiezen de docenten voor PV-panelen, terwijl leerlingen liever geen zonnepanelen hebben. Waarschijnlijk speelt hier het mogelijke nadeel van een minder warm lokaal een rol. Op basis van de resultaten zijn de docenten geneigd eerder de energie-efficiënte technologieën te kiezen in vergelijking met de leerlingen. Er kan worden geconcludeerd dat leraren meer energiebewust zijn dan leerlingen.

ABSTRACT

The focus of this research is on upgrading the level of energy efficiency of primary and secondary school buildings in the Netherlands. The aim of this research is to investigate which energy efficient technologies are technically applicable in school buildings and what are the school building user preferences for these technologies.

In the literature study, several energy efficient technologies are investigated based on the NZEB requirements. These energy efficient technologies can (1) reduce the energy consumption, (2) improve the level of energy efficiency and (3) increase the share of renewable energy. Moreover, considering the abolishment of the net metering scheme, technologies for energy storage are also taken into consideration.

The energy consumption pattern of ten school buildings is described. The ten school buildings are both primary and secondary school buildings. Influencing factors on the energy pattern are identified based on the energy use pattern which are the outdoor temperature, the amount of pupils, the application of solar panels and the implementation of a cooling system.

Thereafter, a panel data regression analysis is conducted on the energy consumption data of the ten schools. The results of this analysis show that the most influencing factors are the education time and the EPC value. In this analysis, some contradictions are shown, probably caused by one of the school buildings. Besides, this analysis includes a small sample size of only ten school buildings.

Finally, the school building user preferences are investigated with a stated choice experiment. The data is collected among teachers of primary and secondary schools, and pupils of secondary schools. The 376 valid respondents were presented 12 choice sets each. Mixed logit modeling is applied for model estimation. The results indicate that, for both pupils and teachers, the ventilation system is the most influencing factor on the choice of a class room. For heating and ventilation, the energy efficient system is chosen above the conventional system. For lighting system and sun blinds, both the pupils and teachers prefer the conventional system above the energy efficient system. For PV panels, the teachers prefer to have PV panels while pupils prefer not as the class temperature may be lower. Based on the results in this questionnaire, it can be concluded that teachers are more energy conscious than pupils.

LIST OF ABBREVIATIONS/GLOSSARY

AAHP:	Air to air heat pump
AWHP:	Air to water heat pump
a-Si:	Amorphous silicon
BENG:	Bijna energiezuinige gebouwen
CCHP:	Combined cooling, heating and power
CHP:	Combined heating and power
COP:	Coefficient of performance
c-Si:	Crystalline silicon
CSP:	Concentrated solar power
EPBD:	Energy Performance of Buildings Directive
EU:	European Union
GHG:	Greenhouse gas
GSHP:	Ground source heat pump
GWHP:	Groundwater heat pump
HPWH:	Heat pump water heater
HTC:	High temperature cooling
HVAC:	Heating, ventilation and air conditioning
IEQ:	Indoor environmental quality
KNMI:	Koninklijk Nederlands Meteorologisch Instituut
LTH:	Low temperature heating
MNL:	Multinomial Logit
MXL:	Mixed Logit
NZEB:	Nearly zero-energy building
PV:	Photovoltaic
RES:	Renewable energy sources
TABS:	Thermally activated building systems
TES:	Thermal energy storage

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1. INTRODUCTION

This chapter describes the background information of the subject and the context in which the research is situated. In addition, the problem definition and the research questions are discussed. Finally, insight is given in the methodology and the research model.

1.1. Background

Environmental issues, such as global warming, ozone layer depletion and air pollution, are seen as concerning problems worldwide (Calabrese et al., 2015; Martins, 2017; Sellami et al., 2016). In the past decades the world's energy consumption increased significantly and it will continue to increase if the energy consumption pattern remains the same (Fouad, Shihata & Morgan, 2017; Sellami et al., 2016; Skandalos & Karamanis, 2015). According to Mostafaeipour et al. (2017), the sea level and the earth's temperature will rise due to continuation of the energy consumption trend. Buildings are the mayor energy consumers worldwide and are responsible for 40% of the total energy consumption (Brandão de Vasconcelos et al., 2016; Cuce, 2016; Dongellini, Naldi & Morini, 2015; Skandalos & Karamanis, 2016). It means that buildings are the leading greenhouse gas (GHG) emitters (Cuce, 2016; Dongellini, Naldi & Morini, 2015; Skandalos & Karamanis, 2015). The European Union (EU) have introduced their energy policy due to environmental problems (Martins, 2017).

These changes in the EU energy policy are made to combat this climate change. In 2009, the European Union has set their 20-20-20 goals for improving the climate (Brunsgaard et al., 2014; Gaglia et al., 2017; Mitka, 2016). By setting these targets, all EU Member States must ensure that 20% less GHG is emitted within the EU, 20% of the EU energy to be generated by renewable energy sources (RES) and 20% energy efficiency improvement by 2020 (Popa, Ion & Popa, 2016). The goal should be achieved in cooperation with all EU Member States (Visser, 2016). In 2030, these targets are set at 40% reduction of GHG emissions in comparison with the level of 1990, 27% share of renewable energy sources and 27% improvement of energy efficiency (European Commission, n.d.).

For the renewable energy target of the Netherlands, 14% of the total energy consumption needs to be produced by renewable energy sources by 2020. The Netherlands are lagging behind on achieving this goal. By 2014, the share of RES was 5.5%, according to D'Adamo & Rose (2016). The Netherlands belongs to the 'Flop five', when it comes to renewable energy production (D'Adamo & Rose, 2016).

1.1.1. Energy Performance of Buildings Directive (EPBD)

The Energy Performance of Buildings Directive (EPBD) is established in 2002 to decrease the amount of energy consumption and to combat the environmental problems. In 2010 the directive has been revised, tightened up and is rearranged to the EPBD recast directive (Majcen, Itard & Visscher, 2013). To integrate renewable sources and to improve energy efficiency of buildings, the European Commission have set standards for every new construction built after the end of 2020. According to the EPBD recast directive, these buildings must be nearly zero-energy buildings (NZEB). It is at the discretion of the EU Member States to translate the requirements of NZEB into their national situations, according to the principle of subsidiarity (Dongellini, Naldi & Morini, 2015; Skandalos & Karamanis, 2015). The Dutch government have set up requirements for nearly zero-energy buildings (in Dutch: bijna energieneutrale gebouwen (BENG)). Requirements for the nearly zero-energy buildings are separated in three categories: energy demand, primary fossil energy consumption and share of renewable energy (Blok, 2015). These requirements have been established for different building features and are displayed in table 1. For governmental buildings, new buildings must be nearly zero-energy building by the end of 2018. All other new buildings must be NZEB by the end of 2020 (RVO, 2017).

Table 1. Requirements for nearly zero-energy buildings in the Netherlands (RVO, 2017)

Building feature	*1. Energy demand (kWh/m².yr)*	*2. Primary fossil energy consumption (kWh/m².yr)*	*3. Share of renewable energy (%)*
Houses and apartment blocks	25	25	50
Utility buildings	50	25	50
Educational buildings	50	60	50
Healthcare buildings	65	120	50

1. Energy demand

With energy demand is meant, the energy consumption only used for building heating and cooling. For utility buildings, the energy consumption of lighting is also taken into account. This energy requirement can be met with both renewable and fossil energy (RVO, 2017).

2. Primary fossil energy consumption

The primary fossil energy consumption consists of the energy consumed for heating, cooling, hot water and fans (if present). For utility buildings, the energy used for lighting is also included. In the calculation of the primary fossil energy consumption, the generated energy is deducted from renewable energy sources (RVO, 2017). For educational buildings and healthcare buildings the requirements are more flexible, according to Van der Heide, Vreemann & Haytink (2016), for healthcare buildings, this is due to the fact that these buildings use more hot water for care purposes.

Difference between energy demand and primary fossil energy consumption

Besides the energy used for hot water purposes and fans (if present), in the calculation of the primary fossil energy consumption, also system losses and auxiliary energy are included. This is not necessary when calculating energy demand (RVO, 2017).

3. Share of renewable energy

The share of renewable energy is calculated in equation 1.1 (RVO, 2017).

$$Share\ of\ renewable\ energy\ (\%) = \frac{Total\ amount\ of\ renewable\ energy\ generation\ (kWh)}{Total\ primary\ fossil\ energy\ consumption\ (kWh) + Total\ amount\ of\ renewable\ energy\ generation\ (kWh)} \quad (1.1)$$

The requirements for nearly zero-energy buildings are not yet been finalized. In 2018, the Dutch government will test the NZEB requirements. If the additional costs for implementing the requirements are at an optimal level, the amendment of the law will be made definitive (RVO, 2017).

1.1.2. Net metering restrictions

In addition to EPBD recast directive, there is also another restriction that affects the energy supply of buildings: the net metering restriction (in Dutch: salderingsregeling). The policy of net metering represents the surplus electricity may be returned to the electricity service provider (utility). The utility must deduct the surplus electricity from the purchased electricity for the same retail rate (Comello & Reichelstein, 2017; Kamp, 2017). The surplus electricity is mainly produced by solar installations.

The amount of solar panels in the Netherlands is increasing rapidly (Kausika, Dolla & Van Sark, 2017). If all these solar installations generate excess electricity from sunrise till sunset, the electricity generation will be higher than the electricity demand during the day time. Therefore, the net metering restrictions in the Netherlands will be abolished after 2023. It is intended that the energy from these renewable sources is stored on-site from 2023 by using batteries so that the energy can be used at a later time (Kamp, 2017).

1.2. Context

A lot of research is conducted in the field of upgrading the level of sustainability and energy efficiency of office buildings (Carlson & Pressnail, 2018; Jia & Lee, 2018). Only a few studies have been conducted on energy efficient school buildings. The studies on smart school buildings that are conducted, are mainly about implementing smart ICT technologies, such as a smart board (Ibrahim, Razak & Kenayathulla, 2013; Taleb & Hassanzadeh, 2015). The EPBD recast directive and the requirements for nearly zero-energy buildings also account for educational buildings. Study on the energy efficiency of school buildings must be conducted before the implementation of the EPBD recast directive. According to RVO (2016), the property of school buildings belongs to school boards, but the municipalities are involved as well as the investment budget for the construction of these buildings will come from municipalities. It is therefore very important that school boards, but definitely also municipalities, have insight in the developments in the field of upgrading the level of sustainability and energy efficiency of school buildings. In addition, these buildings are mainly used by teachers and pupils. It is important, to have a focus on what these people think about the new sustainable developments (Penders, 2017).

1.2.1. Nearly zero-energy school buildings

As mentioned in section 1.1., there are also requirements for educational buildings according to the EPBD recast directive and the nearly zero-energy buildings' requirements. These requirements are shown in table 1 (RVO, 2017). The maximum energy demand for heating or cooling a school building is 50 kWh/m².yr. The school buildings built after the end of 2020 should be provided with insulation that meets these requirements. In addition, the maximum primary fossil energy consumption is 60 kWh/m².yr. The primary fossil energy consumption also includes energy used for lighting, hot water preparation and system losses, as mentioned in subsection 1.1.1. The energy generated from renewable sources may be subtracted from the primary fossil energy consumption. Also, according to the EPBD recast the minimum share of renewable energy must be 50%, for example this energy is generated by solar panels or a heat pump (RVO, 2017).

New buildings must meet the NZEB requirements by the end of 2020. New governmental buildings must be nearly zero-energy by the end of 2018. According to RVO (2017), educational buildings are private institutions with a public duty. Property of school buildings belongs to school boards, according to the educational legislation. For the NZEB requirements, school buildings are not considered as governmental buildings, therefore new built school buildings must be nearly zero-energy by the end of 2020 (RVO, 2017).

1.2.2. Indoor environmental quality of school buildings

In addition to the NZEB requirements for school buildings, it is also important to pay attention on the soft side of this property. The primary function in these buildings is education. According to Turunen et al. (2014), the indoor environmental quality (IEQ) influences the health and well-being of pupils. Poor IEQ eventually causes absence and decreased performance of pupils (Toyinbo et al., 2017). The indoor environmental quality of school buildings is influenced by various building characteristics, for example ventilation and sunlight. According to MacNaughton et al. (2016), relocation to a green building with a better IEQ, pupils experience fewer symptoms of disease. Besides pupils, poor indoor environmental quality influences also the well-being of educators, both physically as mentally (Sadick & Issa, 2017). Upgrading the quality of school buildings is important for the well-being of pupils and educators. Since pupils will eventually run our society, it is important to focus on upgrading the quality of primary and secondary school buildings.

The municipalities and the school board take care of almost 10.000 school buildings in the Netherlands. More than 2.5 million pupils are educated in these primary and secondary schools. Study of Albers et al. (2016) proved that age and functional and technical quality of school buildings vary and the financial resources spent on educational buildings show substantial regional and local differences. This study also investigates that school buildings regularly fail to comply with legal requirements and enforcement does not take place. The current rate at which new constructions are being realized is relatively low: buildings are used on average for 69 years before they are replaced. At a glance for the future, it is needed to investigate the opportunities for new school buildings, because these pupils belong to our future (Albers et al., 2016).

1.3. Research problem and research questions

In this section, the problem analysis and the research questions are discussed. Besides, the objectives and limitations are explained.

1.3.1. Problem analysis and research questions

After the end of 2020, all new school buildings must comply the requirements for nearly zero-energy buildings, according to the EPBD recast directive. According to this recast directive, it is relevant for school boards and municipalities to have knowledge of the improvement of buildings' energy efficiency, reduction of energy consumption and the generation of renewable energy, because standards are set for these three categories. According to abolishment of the net metering restrictions by 2023, it is also useful for school building owners to have knowledge of storing generated energy, because surplus energy cannot be deducted anymore.

Only a few studies have been done about energy efficiency of school buildings. It is therefore relevant to give insight in which energy efficient technologies can be implemented in these buildings. Besides, it is important to understand the preferences of the school building users, such as teachers and pupils.

To figure out what possibilities can be applied in school buildings according to the requirements for nearly zero-energy buildings and which are relevant for users, the following research question is established:

"Which energy efficient technologies are technically applicable in school buildings according to the requirements for nearly zero-energy buildings and what are the school building user preferences for these technologies?"

To answer the main research question, the following sub questions are determined:

I. Which energy efficient technologies can be implemented to decrease the school buildings energy consumption according to the requirements for nearly zero energy buildings?
II. Which technologies can be implemented to improve the school buildings energy efficiency according to the requirements for nearly zero energy buildings?
III. Which technologies can be implemented to increase the amount of renewable energy in school buildings and how can the surplus electricity be stored?
IV. What is the energy consumption pattern of school buildings?
V. Which of the energy efficient technologies are useful according to the energy consumption pattern of school buildings?
VI. Which factors influence the school building's energy consumption?
VII. What are the school building user preferences on the energy efficient technologies?

1.3.2. Research objectives and limitations

The goal of this research is to investigate which energy efficient technologies are relevant for school buildings according to the requirements for nearly zero energy buildings and to give insight in the user preferences of these technologies. The focus of this research refers to new built primary and secondary schools in the Netherlands, but there will also be taken into account that it can be applied to existing school buildings.

1.4. Research design

In this section, the various methodologies of this study will be explained. These methodologies will indicate how the research (sub)questions, identified in section 1.3., will be answered.

1.4.1. Methodological justification

This research consists of six parts: literature study, energy consumption pattern, energy efficient technologies for school buildings, energy consumption analysis, user preferences and conclusion/discussion. In these parts, multiple research methods have been used. The research model is displayed in subsection 1.4.2.

1. Literature study

In chapter 2, the literature study has been conducted. This study gave insight in energy efficient technologies that can be applied in school buildings. These technologies are based on the nearly zero-energy buildings' requirements. This step focused on the three categories: energy demand, primary fossil energy consumption and renewable energy. These energy efficient technologies are divided in multiple building features, such as heating/cooling, ventilation, renewable energy and building automation. According to the abolishment of the net metering restriction, this part also includes technologies for energy storage. After this the energy consumption pattern is described and the user preferences based on energy efficient technologies. For this literature review, scientific articles, theses and websites have been approached. In this chapter the first three sub-questions were discussed.

2. Energy consumption pattern
In chapter 3, the energy consumption pattern of school buildings is determined. This research is conducted by means of ten case studies, which include six primary schools and four secondary schools. These cases are obtained from the smart energy measurement system of HEVO Construction management & consultancy. These school buildings have a smart energy management system which stores and analyses the energy consumption data. This energy consumption pattern will give insight in the energy consumption of the school buildings during summer, winter, day, night, etc. In this part, answer is given on the fourth sub-question.

3. Energy efficient technologies for school buildings
After determining the energy consumption pattern, there is checked if the energy efficient technologies fit this energy pattern. This insight is needed to adjust the energy efficient technologies to the energy consumptions and to make sure the energy sources meets the needs of the energy use of the school buildings. Only the technologies, which benefits the energy consumption will be included in further research. This part will answer sub-question five.

4. Energy consumption analysis
In this part, an energy consumption analysis is carried out. In this analysis the energy consumption data of the ten case studies are collected, together with the school buildings' characteristics. To investigate which factors influence the school buildings' energy consumption, a regression analysis is conducted. In this part, sub-question six is answered.

5. User preferences
Besides the insights in the energy efficient technologies, it is useful to map what the user preferences of these technologies are. In this part a questionnaire is conducted among the teachers of primary and secondary schools and secondary school pupils. In this part, a stated choice experiment is conducted to give insight in the school building user preferences on energy efficient technologies.

6. Conclusion/discussion
The last part will include the conclusions of this study. It will give insight in which energy efficient technologies can be applied in school buildings according to the requirements for nearly zero-energy buildings. Hereby is taken into account what the school user preferences are regarding these technologies. Besides, there is described which factors influence the school buildings energy consumption. This part will answer the main research question of this study.

1.4.2. Conceptual framework

In the previous subsection, the six research parts of this study are explained. Figure 1 on the right, shows the links between the six research parts.

The literature study, together with the energy consumption pattern gives input for the energy efficient technologies that can be applied in school buildings. The energy consumption pattern also gives input in the energy consumption analysis.

The energy efficient technologies are implemented in the questionnaire to give insight in the school building user's preferences. Together with the energy consumption analysis these three parts will give answer to the main research question in the last part.

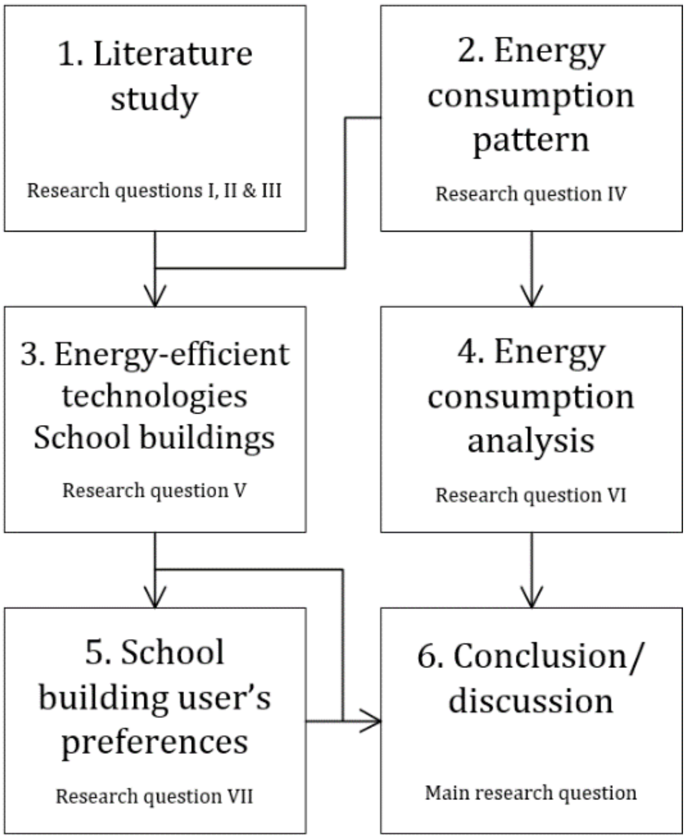


Figure 1. Research model

1.5. The scientifical importance and social relevance of the thesis

For the scientifical importance, there is a research gap on the energy efficiency of school buildings. Only a few studies have been conducted on energy efficient school buildings. The research on smart school buildings that is conducted is mainly about implementing smart ICT technologies. The research is a contribution to the literature. In addition, it is socially relevant to reflect the preferences of the users on the energy efficient technologies. This result will be used to inform the school boards about these preferences. School boards can then use the results for constructing new school buildings or for renovating existing buildings.

1.6. Reading guide

This report consists of five chapters. In the first chapter, the literature review is described. In this chapter multiple energy efficient technologies are discussed. In chapter 3, the energy consumption pattern of school buildings is presented. Chapter 4 contains the energy consumption analysis. In chapter 5, the user preferences on the energy efficient technologies are described. The last chapter contains the conclusions of this research.

2. LITERATURE REVIEW

In the first section of this chapter, state of the art literature is used to identify multiple energy efficient technologies. These technologies are separated in five categories, heating and cooling, ventilation, renewable energy, energy storage and building automation. In section 2, the energy consumption pattern is described and the influencing factors on the energy consumption are explained. In section 3, the user preferences are specified. Finally the conclusions and limitations are described.

2.1. Energy efficient technologies

As described in the first chapter, applying energy efficient technologies is very important, due to environmental issues such as air pollution, depletion of the ozone layer and global warming (Calabrese et al., 2015; Cuce, 2016). According to Benli (2016), economic growth and sustainable development is encouraged by the use of efficient energy sources. So, use of energy-efficient technologies is not only needed for climate concern, but also for improvement of the society.

2.1.1. Technologies heating/cooling

The energy consumption for heating, ventilation and air-conditioning (HVAC) increased rapidly in the past few years to almost 50% of buildings total energy consumption, according to Skandalos & Karamanis (2016). That is why it is vital to increase the use of sustainable and energy-efficient solutions for heating, cooling and ventilation.

2.1.1.1. Radiant ceiling/wall panels

A radiant ceiling/wall panel is a plaster/gypsum or metal panel where heating or cooling of a building is controlled by means of hot or cold water, see figure 2. Couplings are connected to the panels that allow the water to flow along the panel. Energy transfer takes place via radiation (60%) and via convection (Rhee, Olesen & Kim, 2017; Zhang, Liu & Jiang, 2013). These panels are used in both residential and non-residential buildings for heating or cooling (Li et al., 2015; Rhee, Olesen & Kim, 2017).

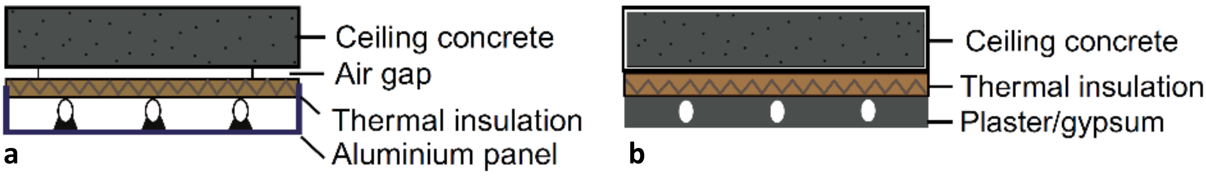


Figure 2. (a) Metal radiant ceiling panel. (b) Plaster/gypsum radiant ceiling panel (Kosonen, 2017)

Radiant ceiling/wall panels are energy efficient and provide a pleasant indoor climate. It causes less draught due to the fact that the air is not blown into the building, but because of the use of radiant heat. In addition, this system ensures more comfort in a building. It produces little to no noise and is very suitable for low temperature heating and high temperature cooling. The system can be equipped with several features, such as ventilation and acoustic solutions (Li et al., 2015; Rhee, Olesen & Kim, 2017; Zhang, Liu & Jiang, 2013). On the other hand, the system has some limitations. Radiant ceiling/wall panels have higher capital costs than convective systems. Installation and adjustment must be done carefully. After installation, it is difficult to check the system and to approach the remaining installations in the ceiling (Rhee, Olesen & Kim, 2017). Also condensation can occur when the surface temperature is lower than the dew point of the air (Bruggema, 2007; Zhang, Liu & Jiang, 2013).

2.1.1.2. Thermally activated building systems (TABS)

Thermally activated building systems (TABS) activates the thermal mass of the building by means of a water supply network that is included in the floors, see figure 3. The water through these pipes is cold if the building needs cooling and warm if the building needs heating. The thermal energy is stored in this way and delivered through the floors and ceilings (Bruggema, 2007; Helsen et al., 2013; Saelens, Parys & Baetens, 2011). TABS can be applied in both residential and non-residential buildings for heating and cooling. It can only be applied in new buildings, not in renovation projects (Kosonen, 2017; Rhee, Olesen & Kim, 2017).

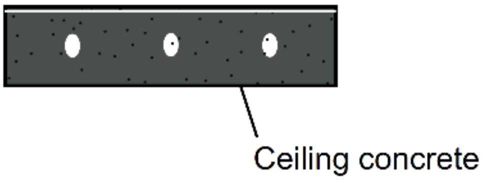


Figure 3. Thermally activated building systems (TABS) (Kosonen, 2017)

Thermally activated building systems provide a high level of comfort by delivering gradual radiation, less affection of draughts and minimum of noise disturbance (Bruggema, 2007; Helsen et al., 2013; Rhee, Olesen & Kim, 2017; Saelens, Parys & Baetens, 2011). According to Kosonen (2017), TABS are energy efficient with the aid of low temperature heating (LTH) and high temperature cooling (HTC). A requirement for TABS with LTH/HTC is that the building must be insulated very well, otherwise heat losses arise. The investment costs of thermally activated building systems are low in comparison with traditional systems (for example underfloor heating), this also applies to the running costs of TABS (Helsen et al., 2013; Kosonen, 2017). If this system is combined with a geothermal heat pump, the system is called GEOTABS, a very energy efficient solution (Kosonen, 2017; Rhee, Olesen & Kim, 2017). TABS are delivering heat/cold radiation both up via the floor and down via the ceiling. This has also disadvantages, if two spaces located one above the other and have different heat demands. Heating and cooling for individual spaces is also an issue (Bruggema, 2007; Saelens, Parys & Baetens, 2011). While developing a building with TABS, extra attention must be drawn to the design, both for the layout and the acoustics. Acoustic facilities cannot be processed into the ceiling. Besides, thermally activated building systems has a slow operation. In some cases, an additional heating system is required during peak demand (Bruggema, 2007; Kosonen, 2017; Rhee, Olesen & Kim, 2017). Also, according to Van de Cruijs (2009), TABS cannot be applied in renovation projects.

2.1.1.3. Low temperature heating (LTH)

Low temperature heating (LTH) is used for heating a building by means of warm water. In comparison to traditional heating, LTH uses water with a much lower supply temperature. Traditional heating uses water with a temperature from 55 to 90 °C, LTH uses water temperatures from 30 to 55 °C (Jiang et al., 2015; Østergaard & Svendsen, 2016). To be energy efficient, LTH must be applied with large surface heat emitters (for example radiant ceiling panels, TABS or low temperature radiators) to make sure the building can be heated with low temperatures. It is also necessary to apply LTH only in very well insulated buildings, to reduce heat losses (Hesaraki, Ploskic & Holmberg, 2015).

Low temperature heating provides a comfortable and healthy indoor environment with less air movement, due to a stable, even and pleasant ambient temperature. The system is environmental friendly and very energy efficient, when using large surface heat emitters (Hesaraki, Ploskic & Holmberg, 2015; Jiang et al., 2015; Østergaard & Svendsen, 2016). A limitation of this system is, that it is difficult to apply in renovation projects with convective heating systems (Østergaard & Svendsen, 2016).

2.1.1.4. High temperature cooling (HTC)

High temperature cooling (HTC) is way of cooling a building with cold water, the same as traditional cooling systems. The difference between HTC and traditional cooling systems is the amount of degrees of the supply temperature. The supply temperature of HTC systems is much higher. Traditionally water/liquid with a temperature of 6 °C is used, with HTC the temperature of the water is between 10 to 16 °C. The temperature of HTC is thus considerably higher (Saber, Wai Tham & Leibundgut, 2016; Zhai et al., 2015). High temperature cooling can also be used such as low temperature heating only in cooling systems with a larger surface area, to make sure LTH is efficient (Zhai et al., 2015).

High temperature cooling is used to make buildings more energy efficient. When used in well insulated buildings, HTC will provide energy savings. It also ensures a comfortable and healthy indoor environment, because of the gradual space cooling (Jiang et al., 2015; Liu et al., 2017; Zhai et al., 2015). In combination with radiant ceiling panels, it reduces the chance of condensation (Saber, Wai Tham & Leibundgut, 2016).

2.1.1.5. Cogeneration or combined heat & power (CHP)

Cogeneration or combined heat & power (CHP) is a method of heat generation that generates both electricity and heat with a single fuel. The electricity is released during the generation of heat. This can be based on natural gas, petroleum or even pellets. Cogeneration works the same as a common boiler, if the heat is needed, the boiler will turn on. In addition to heat, the CHP also generates electricity at the same time (Al Moussawi, Fardoun & Louahlia, 2017; Siler-Evans, Granger Morgan & Azevedo, 2012; Strachan & Farrell, 2006). This heat generation system can be applied both in residential buildings as in larger non-residential buildings. In residential buildings the system is applied as a micro-CHP system. It is a smaller system usable by one household (Al Moussawi, Fardoun & Louahlia, 2017).

Advantages of combined heat & power are that only one system is used for both heat and electricity. The system is more efficient than central energy stations. The greenhouse gas emissions are lower in comparison with conventional energy generators (Gvozdenac et al., 2017; Siler-Evans, Granger Morgan & Azevedo, 2012; Strachan & Farrell, 2006). The heat generation system is energy efficient and reduces costs (Al Moussawi, Fardoun & Louahlia, 2017; Gvozdenac et al., 2017). Disadvantages of cogeneration is that the heat and electricity generation must be adjusted, otherwise too much unnecessary energy is produced and will be lost (Siler-Evans, Granger Morgan & Azevedo, 2012).

2.1.1.6. Trigeneration or combined cooling, heat & power (CCHP)

Trigeneration or combined cooling heating and power (CCHP) is a heat generation system which initially generates heat and electricity, the same as with a combined heating and power (CHP) system. The heat produced by this generator can be partly converted into cold by means of an absorption chiller. By means of this application, this cooling can be used for air-conditioning. This system can be used in both residential as larger non-residential buildings. For the residential building micro-CCHP systems are used (Al Moussawi, Fardoun & Louahlia, 2017; Ebrahimi & Keshavarz, 2013; Farahnak et al., 2015; Siler-Evans, Granger Morgan & Azevedo, 2012).

According to Siler-Evans et al. (2012), CCHP can produce heat for heating in the winter and cooling for air-conditioning in the summer. Trigeneration is also saving energy costs, flexible and reducing greenhouse gas emissions (Ebrahimi & Keshavarz, 2013; Farahnak et al., 2015). This system is more expensive than CHP, because of the additional absorption chiller (Siler-Evans, Granger Morgan & Azevedo, 2012).

2.1.2. Technologies ventilation

2.1.2.1. Balanced heat recovery systems

In the case of balanced heat recovery ventilation, both the amount of fresh air supply as the amount of polluted indoor air are equal. Heat recovery ensures by means of a heat exchanger, that the heat of the exhausted air is used to heat the fresh air (El Fouih et al., 2012; Fernándes-Seara et al., 2011; Guillén-Lambea, Rodríguez-Soria & Marín, 2017). This ventilation system can be used in both residential as non-residential buildings (El Fouih et al., 2012; Guillén-Lambea, Rodríguez-Soria & Marín, 2017).

Balanced heat recovery systems provide more comfort in the building and reduce the amount of heat losses. By means of the heat exchanger, this system saves energy, because the heat of the exhaust air is re-used for heating the fresh air. According to El Fouih et al. (2012) a requirement for this system is that the building must have high thermal insulation and air tightness. Besides, opening windows is still necessary to increase the amount of fresh air. The investment costs of this heat recovery system are much higher than traditional systems. Also energy savings are up against the energy usage of the ventilators of the mechanical ventilation system (El Fouih et al., 2012; Fernándes-Seara et al., 2011; Guillén-Lambea, Rodríguez-Soria & Marín, 2016; Guillén-Lambea, Rodríguez-Soria & Marín, 2017).

2.1.2.2. Earth-air tube ventilation

Earth-air tube ventilation is a method whereby heat or cold is extracted from the soil to heat or cool the supplied ventilation air, see figure 4 below (Yang & Zhang, 2015). At 1.5-2 meters, horizontal tubes are used as heat exchanger for warming the supplied air in the winter and cooling the supplied air during summer (Baglivo & Congedo, 2017; Gan, 2014, 2015, 2017; Yang & Zhang, 2015). Earth-air tube ventilation was originally applied to greenhouses, but is now also used in residential and commercial buildings (Gan, 2014).

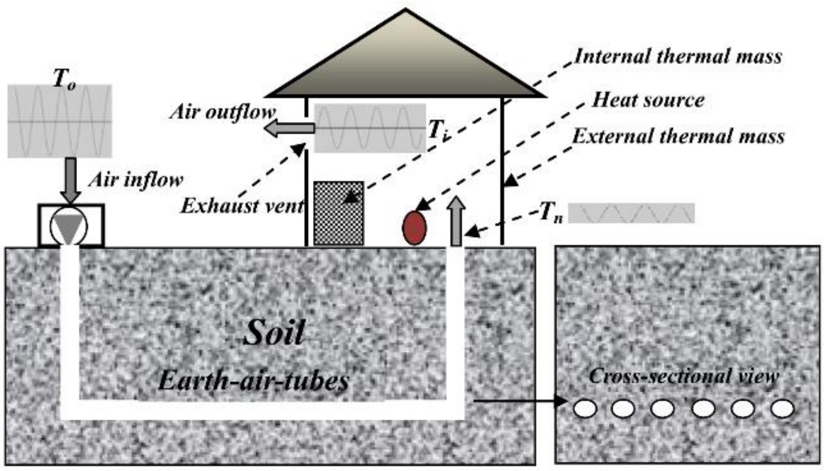


Figure 4. Schematic view of an earth-air tube ventilation system (Yang & Zhang, 2015)

According to Gan (2015), earth-air tube ventilation reduces energy costs for heating and cooling. It provides a better comfort, because the supply air is constant (Yang & Zhang, 2015). It is also very energy efficient, because it uses warmth of the soil to warm up the ventilation air (Baglivo & Congedo, 2017; Gan, 2014, 2015, 2017). However, Gan (2014, 2015, 2017) proved that earth-air tube ventilation can cause moisture problems through the underground tubes. Also a large site is required to install the underground system (Baglivo & Congedo, 2017).

2.1.2.3 Bauer Optimalisation ventilation technology
Bauer Optimalisation is a climate control technology without directed ventilation flow. This system uses a slow, non-directional, chaotic airstream (De Installatie Adviseur, 2015; Lieshout, 2013). This ventilation technology uses sensors to control the ventilation requirement (Theodoridou & Valk, 2015). The technology is mainly applied in public buildings and atriums (De Installatie Adviseur, 2015).

Limited scientific research is conducted on this innovative ventilation technology. According to Theodoridou & Valk (2015), this is due to a patent on the technology. Bauer Optimalisation ventilation systems provide no draught, an optimal comfort and energy savings (De Installatie Adviseur, 2015; Lieshout, 2013). The critical review of Theodoridou & Valk (2015) specified that energy savings cannot be mentioned as an advantage, because the investment costs are not declared. Besides, the installation procedure is complicated and there are still some problems in practice with this ventilation system (De Installatie Adviseur, 2015).

2.1.3. Technologies renewable energy sources (RES)
Renewable energy is seen as the problem solver for the environmental problems, such as global warming and ozone layer depletion (Foaud, Shihata & Morgan, 2017; Sellami et al., 2016). But it is also a solution for the finite stocks of fossil fuels, because it provides clean, secure and affordable energy (Benli, 2016; Kim et al., 2016; Martins, 2017). Renewable energy includes among others aerothermal, geothermal and hydrothermal energy, solar energy and wind energy (Dongellini, Naldi & Morini, 2015; Vasseur & Kemp, 2015).

2.1.3.1. Heat pump
A heat pump consists of four processes which are continuously repeated: the evaporator, the compressor, the condenser and the expansion valve, see figure 5. Through these four parts a cooling fluid is pumped around. In the evaporator, the liquid is heated. For this heating, heat is extracted from the heat source (air, water or ground). The liquid absorbs the heat, boils and evaporates, the liquid is now turned into vapour. The pressure of this vapour is then increased in the compressor, causing the temperature to increase rapidly. This warm vapour emits warmth to a liquid used for the central heating. Then the vapour enters the condenser, where the vapour is converted into liquid again. Finally, the fluid enters the expansion valve, which also reduces the pressure, this will also cause a drop in temperature. After that, the liquid is suitable for repeating the process again (Rees, 2016; Sarbu & Sebarchievici, 2016).

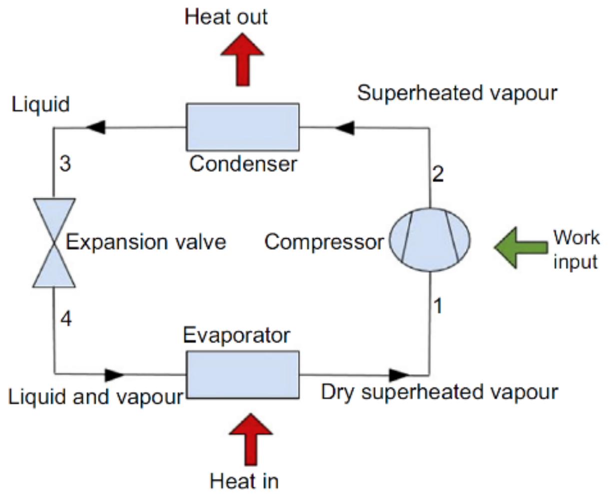


Figure 5. Schematic diagram of the operation of a heat pump (Rees, 2016)

2.1.3.2. Geothermal heat pumps

Geothermal heat pumps use the heat of the soil as a heat source for the heat pump (Yoon, Lee & Go, 2015). Geothermal heat pumps are used with open and closed sources. An open source heat pump is a heat pump which uses open pipelines. This heat pump pumps the groundwater through these open pipes, extracts the heat from it and pump the used groundwater back into the soil. This heat pump is called a ground water source heat pump (Dasare & Saha, 2015). The closed source heat pumps uses a closed pipeline system. In these systems fluids passes through the pipes. The liquid does not come in contact with the soil. It only extracts heat from the soil. This can be done by using horizontal or vertical pipe systems (Dasare & Saha, 2015; Yoon, Lee & Go, 2015).

Geothermal heat pumps benefit from the uniform and stable temperature of the ground(water). Therefore, these heat pumps are very energy efficient (Dasare & Saha, 2015; Kim et al., 2016; Li et al., 2017; Luo et al., 2017; Yoon, Lee & Go, 2014, 2015). Besides, geothermal heat pump have lower operation costs in comparison with traditional heating systems and due to the use of renewable energy geothermal heat pumps reduce greenhouse gas emissions (Dasare & Saha, 2015; Lu et al., 2017; Madessa et al., 2017; Shang, Dong & Li, 2014). According to Adamovsky et al. (2015) ground source heat pumps are complex systems and more difficult to install relative to aerothermal heat pumps. Ground source heat pumps have also higher investment costs in comparison with air source heat pumps (Adamovsky, Neuberger & Adamovsky, 2015; Lu et al., 2017).

2.1.3.2.1. Horizontal ground source heat pump

Horizontal Ground Source Heat Pump (GSHP) is a heat pump with a horizontal pipe network. The pipes in the heating network are placed at a depth of 1-2 meters, see figure 6. Through these pipes, liquid flows that attracts the heat of the soil (Adamovsky, Neuberger & Adamovsky, 2015; Dasare & Saha, 2015; Li et al., 2017). According to Kim et al. (2016) heat absorption of horizontal GSHP is improved by rainfall and sunshine. This system emits heat to the soil in the summer and absorbs heat during winter. Dasare & Saha (2015) mentioned that these heat pumps are mainly used in rural area with a low urban density. Because the Netherlands is densely populated, this can be seen as a limitation.

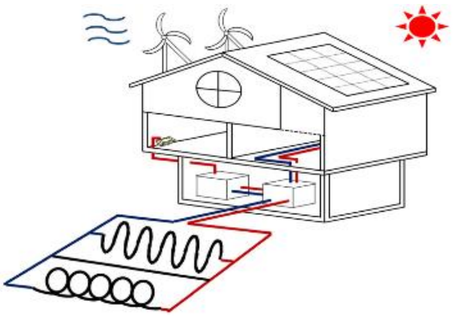


Figure 6. Horizontal ground heat exchanger with different pipe configurations (Yoon, Lee & Go, 2015)

According to Dasare & Saha (2015), horizontal GSHP's can be seen as an economic choice, if there are no limits on land usage. Horizontal GSHP has lower installation costs than vertical systems, because excavations are less expensive than drilling boreholes (Dasare & Saha, 2015; Li et al., 2017; Yoon, Lee & Go, 2015). This system is a compromise between efficiency and costs, because it is not the most expensive system but it has not the highest coefficient of performance (COP) (Adamovsky, Neuberger & Adamovsky, 2015; Dasare & Saha, 2015; Kim et al., 2016; Yoon, Lee & Go, 2015). The COP values differ between several locations because of differences in moisture and mineralogical composition of the soil. Efficiency of the horizontal ground source heat pumps are also influenced by the pipe configuration, the type of pipe and the depth (Adamovsky, Neuberger & Adamovsky, 2015; Dasare & Saha, 2015; Kim et al., 2016; Yoon, Lee & Go, 2015). By using this type of heat pump, a large surface area is required for excavation of the soil (Dasare & Saha, 2015; Kim et al., 2016).

2.1.3.2.2. Vertical ground source heat pump

A vertical ground source heat pump consist of three components: the heat pump, the ground heat exchanger and indoor units. These components provides that the thermal energy of the soil is used for the heating or cooling of a building. A circulation fluid is passing through the ground heat exchanger. During winter, it extracts the heat of the ground to warm up the building and in the summer it uses the cold of the ground for cooling, see figure 7 below (Lu et al., 2017; Luo et al., 2017; Madessa et al., 2017). According to Lu et al. (2017), the boreholes are typically less than 100 meters, but other research specified that the most commonly used depth for the vertical GSHP is between 150-200 meters (Kim et al., 2016; Yoon, Lee & Go, 2014, 2015).

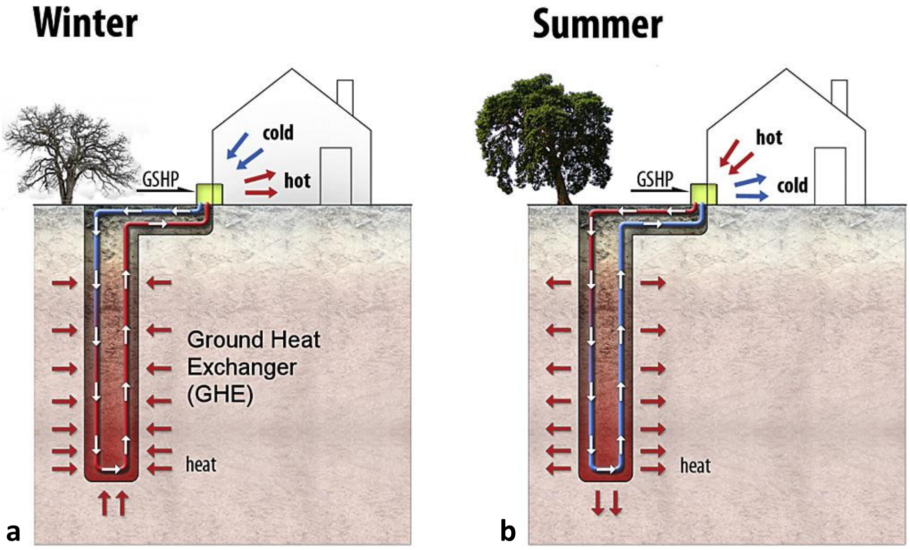


Figure 7. (a) The principle of a vertical ground source heat pump system during winter. (b) The principle of a vertical ground source heat pump system during summer (Lu et al., 2017).

Vertical GSHP is the most efficient system in comparison with other heat pumps and for this system is only a small surface area needed (Adamovsky, Neuberger & Adamovsky, 2015; Dasare & Saha, 2015; Kong et al., 2017). According to Kong et al. (2017), the vertical GSHP is the most popular heat pump in high densely populated areas. Limitations of these vertical systems are that the installation costs are much higher, because of the deep boreholes. Also implementation of this system is not always possible due to groundwater protection areas (Adamovsky, Neuberger & Adamovsky, 2015; Dasare & Saha, 2015; Galgaro & Cultrera, 2013; Kim et al., 2016; Kong et al., 2017; Li et al., 2017; Yoon, Lee & Go, 2014; 2015).

2.1.3.2.3. Groundwater heat pump (GWHP)

As mentioned above, a groundwater heat pump operates with an open source. Groundwater is pumped from the aquifer through the heat exchanger. After extraction of the heat, the groundwater is re-injected into the aquifer (Galgaro & Cultrera, 2013; García-Gil et al., 2016). According to Zhou et al. (2013), the groundwater is a heat source in the winter and a heat sink during the summer.

Advantages of groundwater heat pumps are: 1) the high efficiency due to a constant groundwater temperature (Sciacovelli, Guelpa & Verda, 2014); 2) operational and energy usage is lower than traditional systems (Zhen et al., 2017) and 3) in comparison with other ground source heat pumps it has higher energy density, faster transport and lower costs (Zhou et al., 2013). Limitations of GSHP's are that it is not applicable at any location, because it requires an aquifer (Galgaro & Cultrera, 2013). According to Sciacovelli et al. (2014), temperature difference between the pumped water and the re-injected water can influence the performances of other heat pumps in the neighborhood. Just as vertical GSHP's, implementation of this system is not always possible due to groundwater protection areas (Galgaro & Cultrera, 2013).

2.1.3.3. Aerothermal heat pumps

Aerothermal heat pumps uses the ambient air as heat source. Two types are distinguished, air to air heat pump (AAHP) and air to water heat pump (AWHP). These two systems can use both outdoor air and exhaust air extracted from the building. Exhaust air-to-air heat recovery systems are used as ventilation system and is already explained in subsection 2.1.2.1. Aerothermal heat pumps have lower investment costs than geothermal heat pumps, but the efficiency of these systems are also lower (Naldi, Dongellini & Morini, 2015; Thalfeld, Kunitski & Latõšov, 2018).

2.1.3.3.1. Air to air heat pump (AAHP)

An air to air heat pump (AAHP) is a heating system by using air heating. With the aid of warm air flow the building is being warmed up. This system consist of an outside and an inside unit. The outside unit extracts heat of the outdoor air, the inside unit ensures that the heat is transferred to the heating air which flows into the building. This system can be applied as heating system and both as ventilation system in small dwellings, but also in large commercial buildings (Calabrese et al., 2015; Kim, Choi & Kim, 2015; Mortada et al., 2012).

Advantages of this system are, also for the other air source heat pumps, 1) simple to install; 2) high energy saving potential and 3) efficient solution (Ma et al., 2017; Tran et al., 2013). Besides, for air to air heat pumps, it is more comfortable and more quickly warmed up, due to air heating (Gram-Hanssen, Christensen & Petersen, 2012). Disadvantages of air source heat pump system is that it is 70% less efficient in cold temperature climates than in warm temperature climates (Mortada et al., 2012).

2.1.3.3.2. Air to water heat pump (AWHP)
An air to water heat pump (AWHP) uses the same principle as an air to air heat pump, but instead of heating air, this heat pump system heats water for heating or cooling purposes (Madonna & Bazzocchi, 2013). This system can also be used for tap water heating. Advantages and disadvantages are similar to air to air heat pumps.

2.1.3.3.3. Heat pump water heater (HPWH)
A heat pump water heater is just like an air to water heat pump system, but instead of using outdoor air as heat source the heat pump water heater uses exhaust air (Kensby, Trüschel & Dalenbäck, 2017). According to Vieira, Steward and Beal (2015), air source heat pump water heaters are the most popular systems for water heating purposes. Advantages of HPWH are the lower implementation costs than other heat pump boilers and it has also a less complex system. Disadvantages of this systems are the higher initial costs in comparison with other water heating systems and this system is not able to heat water on high demand. (Vieira, Steward & Beal, 2015; Wanjiru, Sichilalu & Xia, 2017; Willem, Lin & Lekov, 2017).

2.1.3.4. Solar energy
Solar energy is the largest renewable energy sources of all renewable energy sources (Vasseur & Kemp, 2015). This is because solar energy is available and feasible in many countries all over the world (Fouad, Shihata & Morgan, 2017; Martins, 2017). Besides that, according to Comello & Reichelstein (2017), the implementation of solar energy sources has grown rapidly in the past few years due to government subsidies. Solar energy can be captured by photovoltaic (PV) modules.

PV's are able to transform sunlight directly into electricity (Skandalos & Karamanis, 2015), by means of among other solar panels. PV modules are common made of crystalline silicon (c-Si) or amorphous silicon (a-Si) (Gaglia et al., 2017). These silicon PV modules, are wafers with dimensions of 10 cm x 10 cm x 0.3 mm. The wafers consists of 2 layers of silicon with an electric field built-in it, which captures the energy from sunlight. If the solar energy captured by the electric field is above an amount of energy, the solar energy will be transformed into electricity by means of photons and electrons (Fouad, Shihata & Morgan, 2017).

2.1.3.4.1. Photovoltaic (PV) panels
Photovoltaic (PV) panels are panels filled with silicon PV wafers. PV wafers convert light into direct current. With the aid of a converter, direct current is transferred into alternating current, it is then converted in a useful form of electricity (Fouad, Shihata & Morgan, 2017). According to Verhees et al. (2013), PV panels are likely to be the most important renewable energy source after 2010. PV panels also absorb energy on a cloudy day, only if the panels are covered with snow or leafs, they do not perform well.

Advantages of PV panels are their efficiency and energy saving potential. And according to Gaglia et al. (2017), the silicon cells are warranted for 25 years. Disadvantages of this electricity generating system are that the efficiency depends on the performance of the materials. Amorphous silicon wafers are thinner and less expensive than crystalline silicon wafers, but they are also less efficient (Gaglia et al., 2017; Martins, 2017).

2.1.3.4.2. Photovoltaic (PV) glazing

In the past decades, glazing technologies, such as windows, are more often used in facades due to their main benefit: providing daylight (Skandalos & Karamanis, 2015; Wang et al., 2016). But, windows also ensure more heat loss in wintertime in comparison to other building elements, due to their higher U-value (Cuce, 2016; Skandalos & Karamanis, 2015; Wang et al., 2016). In summertime, windows can provide problems such as overheating, due to their lower insulation capacity.

Photovoltaic (PV) glazing can block the heat of the sun and at the same time generate electricity (Cuce, 2016; Skandalos & Karamanis, 2015; 2016; Wang et al., 2016; 2017). PV windows consists of two layers of glass filled with a PV cell captured in two ethylene vinyl acetate (EVA) sheets, a layer of reflection glass and an air gap, see figure 8 below (Skandalos & Karamanis, 2015; Wang et al., 2017). PV windows are by now mainly used in office buildings, but also in residential and other commercial buildings (Cuce, 2016; Wang et al., 2016).

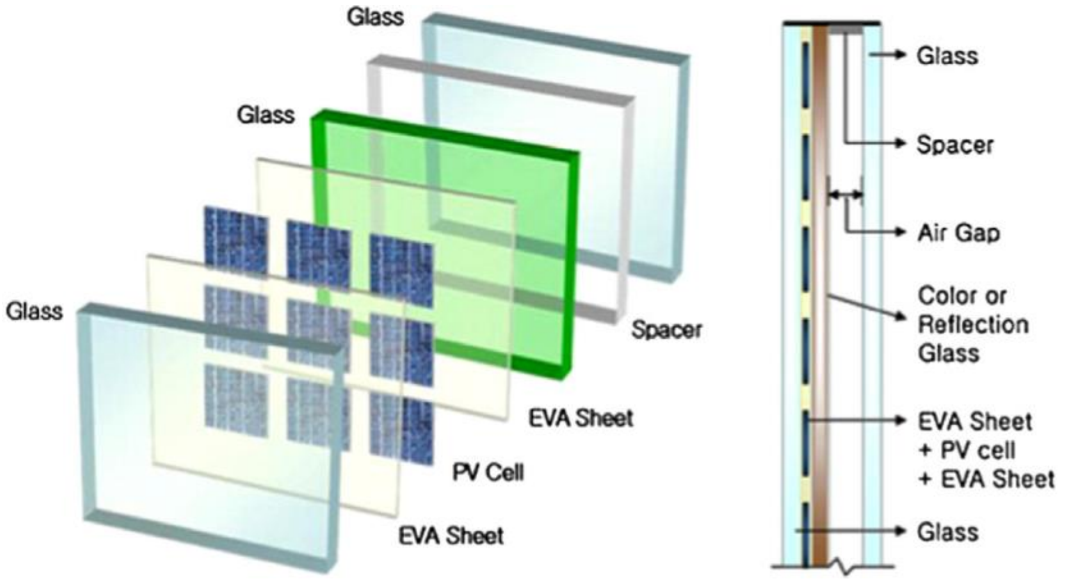


Figure 8. Schematic diagram of a PV window with crystalline silicon (c-Si) wafers (Skandalos & Karamanis, 2015)

Besides electricity generation and blocking sunlight, there are more advantages of PV glazing. According to Skandalos & Karamanis (2016), by blocking heat of the sun, also cooling loads are reduced what maintains into energy savings for air conditioning. PV glazing is also useful in renovation projects, because of the simple installation and replacement of traditional glazing (Cuce, 2016; Wang et al., 2016). Contrary to the advantages, PV glazing has also downsides. Wang et al. (2016) mentioned that it provides less visibility to the external environment. It is also an expensive technology due to the high initial costs of silicon PV cells (Cuce, 2016). And at least, the integration of the PV windows must be extensively investigated in both new and existing buildings due to the building energy balance (Skandalos & Karamanis, 2016).

2.1.3.4.3. Solar water heater

Water heating is after heating, cooling and lighting the largest energy consumer in commercial buildings (Zou et al., 2017). Since the uprising awareness of renewable energy sources, solar water heaters have become more popular (Sellami et al., 2016). Solar water heaters uses solar energy by means of solar collectors for water heating purposes (Mostafaeipour et al., 2017; Sellami et al., 2016). After the water is heated by the sun, it is stored into an insulated water tank. This tank is needed to provide hot water in times when there is lack of sunshine. Besides a storage tank and solar collectors, transfer pipes and a circulation system are necessary, see figure 9 below (Mostafaeipour et al., 2017; Sellami et al., 2016).

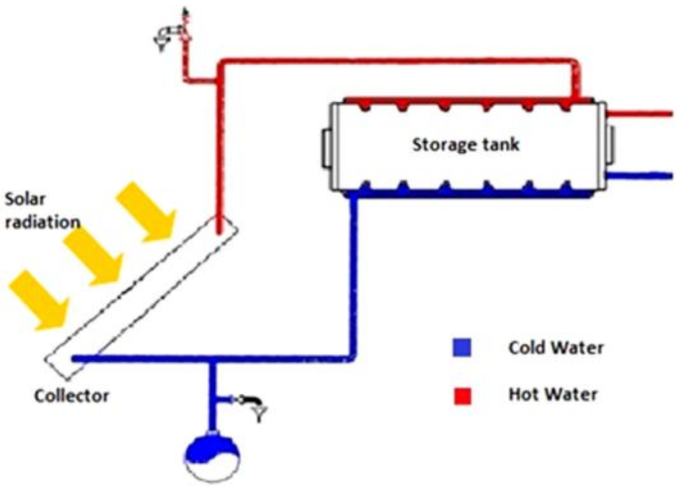


Figure 9. Schematic diagram of a solar water heater with a passive system (Sellami et al., 2016)

Solar water heaters are widely used in various building sectors, also in the educational sector. Sellami et al. (2016) proved that using solar water heaters in this sector, not only provide hot water, but also give insight in the operation of such sustainable techniques. Of all the solar energy technologies, solar water heaters have the simplest technique and are the most affordable (Sellami et al., 2016). It has potential to save up to 38% of the energy supply. Solar water heaters are mainly used for small-size consumption and they must have access to a large storage tank. Payback time of this system varies through different countries, it is very affordable in the South of Europe, due to the warm climate (Mostefaeipour et al., 2017).

2.1.3.5. Wind energy
Another renewable energy source is wind energy, as it says it captures energy from the power of the wind. According to Martins (2017), wind energy is together with solar energy the main renewable energy source for electricity generation. For wind energy generation, not only large wind turbines are available, also small systems consists used for a single building electricity generation (Taylor et al., 2013).

2.1.3.5.1. Micro-wind turbine
A micro-wind turbine is such a small system which captures energy and transfers it into electricity. Wind turbines can be categorized into 3 types: large wind turbines, small wind turbines and micro-wind turbines. Large wind turbines, with a hub height of around 105 meters and a diameter of 90 meters, can produce 3000 kW per hour, these turbines can be used for electricity generation of a whole community (Breeze, 2016; Taylor et al., 2013). Small wind turbines are specified in different ways, generally they are specified as wind turbines with a height up to 30 meters and a production from 1 to 10 kW per hour. These wind turbines can be installed roof-mounted or free-standing (Breeze, 2016; Grieser, Sunak & Madlener, 2015). Micro-wind turbines produce up to 1 kW per hour and can be used to supply a small

building with electricity. These turbines are mainly roof-mounted and produced in various heights, generally with blades of maximum 2 meters (Breeze, 2016; Ledo, Kosasih & Cooper, 2011; Taylor et al., 2013).

Generally, wind turbines are mainly applied in rural areas or off-grid systems, but nowadays also more and more in urban areas (Grieser, Sunak & Madlener, 2015). Micro-wind turbines generates electricity in a usable form and in addition this system provides a high degree of technical reliability (Grieser, Sunak & Madlener, 2015; Ledo, Kosasih & Cooper, 2011). Linked to a battery storage system, micro-wind turbines can supply continuous power generation (Breeze, 2016). Disadvantages of these wind turbines are the high levels of noise generated by the turbines and the limited performance in urban areas. The higher the density in these areas leads to decrease in electricity generation (Abohela, Hamza & Dudek, 2013; Breeze, 2016; Grieser, Sunak & Madlener, 2015; Taylor et al., 2013).

2.1.4. Technologies for energy storage

Many renewable energy sources, mainly solar energy and wind energy, produce energy on moments when no electricity is needed. Also, solar and wind energy is unpredictable and uncontrolled (Reddy et al., 2018). This provides, in combination with the probable abolition of the net metering restrictions, as mentioned in the first chapter, that it will be more important to storage electricity (Comello & Reichelstein, 2017). In this section, a few possible energy storage systems are specified.

2.1.4.1. Thermal energy storage

Thermal energy storage can be used for two main purposes, storage of heat/cold thermal energy or storage of electricity. Storage of heat/cold thermal energy can also be seen as a geothermal heat pump, by using an aquifer for extracting heat/cold (Lizana et al., 2018; Sommer et al., 2015). These types of thermal energy storage have been discussed in subsection 2.1.3.2. Thermal energy storage for electricity storage purposes are explained in this subsection.

Thermal energy storage (TES) systems consists of a boiler in which heat or cold thermal energy is stored, which can be used later for electricity generation (Davenne et al., 2017; Reddy, Mudgal & Mallick, 2018). TES systems consists mainly of a closed circuit filled with gas, which flows through the compressor and the expander and exchanges heat or cold with the hot or cold boilers, see figure 10. The three most important modes of these TES systems are: direct energy transmission, charging mode and discharge mode (Davenne et al., 2017). This system is by now mostly used for high consumption combined with a field of solar panels, this is called a concentrated solar power (CSP) plant (Alva, Lin & Fang, 2018; Davenne et al., 2017; Reddy, Mudgal & Mallick, 2018).

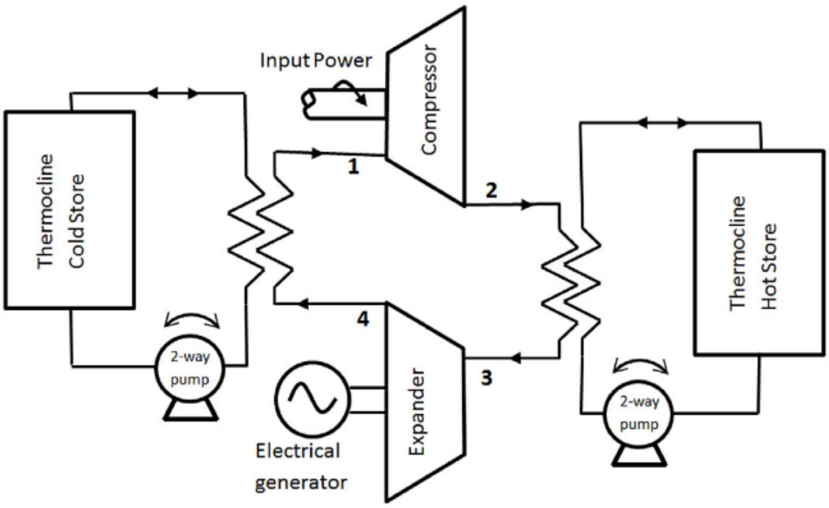


Figure 10. Schematic diagram of a thermal pumping cycle (Davenne et al., 2017)

Advantages of this system is that it is an efficient method for energy storage, it has a better life cycle and is more durable (Alva, Lin & Fang, 2018; Davenne et al., 2017). TES are also able to storage energy directly, because it does not have to be converted in another form of energy (Reddy, Mudgal & Mallick, 2018). But this system has also disadvantages, namely as mentioned before it is by now mainly used for high consumption purposes. Also it is, in comparison with batteries, less suitable for energy storage from wind and solar energy sources (Alva, Lin & Fang, 2018).

2.1.4.2. Battery energy storage
Battery energy storage systems are used to store energy generated by renewable energy sources such as solar panels. It is stored during periods of high generation and can be later used during peak hours (Prada et al., 2017; Vieira, Moura & de Almeida, 2017). The three main types of battery systems are: lead acid, sodium-nickel-chloride and lithium ion. Lithium ion batteries are proved to perform the best in comparison with the other two types (Vieira, Moura & de Almeida, 2017). Battery energy storage systems can be applied in both commercial buildings and dwellings (Nair & Garimella, 2010).

Due to the battery energy storage, less generated energy is being wasted. By storing the energy in batteries, there are also less energy costs during peak hours. Because of this system, more and more efficient cleaner energy can be used (Nair & Garimella, 2010). On the other hand, this technology is uncertain and challenging, due to the capacities, energy yields and investment costs (Mariaud et al., 2017). Moreover, the batteries are made of toxicities, which are not sustainable (Alva, Lin & Fang, 2018).

2.1.4.3. Smart grid
Another way to storage energy generated by renewable energy sources, is by means of a smart grid. A smart grid is an electricity network connected with electricity generators and electricity consumers. This network can be locally distributed, but it can also be arranged regionally or nationally (Bulut et al., 2016; Lawrence et al., 2016). Within a smart grid, buildings are connected with each other. If more electricity is generated than needed, other buildings on the grid can use this electricity for their own consumption (Lawrence et al., 2016).

Benefits of buildings in a smart grid are cost minimization and energy-efficiency (Lawrence et al., 2016). But smart grids have also drawbacks. It creates uncertainty for the consumers and it is a source of energy losses before reaching the end-user (Nair & Garimella, 2010; Vieira, Moura & de Almeida, 2017). Also the smart grid must be available at the location, or else a grid must first be implemented (Lawrence et al., 2016).

2.1.5. Technologies building automation

Energy efficiency of buildings can be optimized with building automation technologies. Compared to other implemented technologies, implementing these building automation technologies is simple and quick and it is one of the most cost effective ways (Nagy et al., 2015).

2.1.5.1. Automatic lighting

Automatic lighting is based on occupancy behavior by means of motion sensors. If a motion is detected, the lighting automatically switch on. And if no motion is detected for an amount of time, the lighting is switched off. Advantages of this technology are that it reduces energy consumption and it saves energy costs. It can save up to 38% of energy in comparison with manual lighting systems. Drawbacks of automatic lighting is that if someone is out of reach of the motion sensors or is not moving, the lights will be switched off (Nagy et al, 2015).

2.1.5.2. Automatic sun blinds

Automatic sun blinds are controlled by using sensors for indoor illuminance. The blinds will be lowered if there is a high level of illuminance and otherwise this level is low (Gunay et al., 2017). Advantages of automatic sun blinds are savings on cooling load, because of automatic shading, more warmth of the sunlight is blocked. This will lead to less energy consumption of the cooling system. Drawbacks of this technology is that occupants are annoyed if the sun blinds are lowered if it still feels glary, and otherwise if it feels bright (Gunay et al., 2017).

2.1.5.3. Automatic daylight control

Automatic daylight control is a technology to control the illuminance of the lighting system. The lighting illuminance is dimmed automatically based on the daylight illuminance (Meerbeek et al., 2014; Taleb & Mannsour, 2012). This technologies saves the energy consumption, is more energy efficient and provides occupant comfort (Nagy et al., 2015; Taleb & Mannsour, 2012).

In appendix A, a summary of the advantages and disadvantages of the energy efficient technologies is included.

2.2. Energy consumption

To apply energy efficient technologies, the energy consumption pattern will change. The energy consumption will decrease due to the more efficient use of energy. In this section, the energy consumption pattern of commercial buildings will be investigated and after that the influencing factors on the energy consumption of buildings will be described.

2.2.1. Energy consumption pattern of commercial buildings

The energy consumption pattern shows the amount of energy consumed during each hour of the day. In this energy consumption pattern the weekends are not taken into account. According Menezes et al. (2014), the amount of energy consumption of commercial buildings is around 10% in comparison with weekdays. If the weekends are taken into account the average energy consumption during the day will be lower and not realistic for weekdays. In figure 11, the energy consumption pattern of small office buildings is displayed (Menezes et al, 2014). This energy consumption in measured and predicted based on weekdays. The measured energy consumption is displayed as black lines and the predicted energy consumption in grey lines. In figure 11 can be seen that most of the energy is consumed between 8 o'clock in the morning and 8 o'clock in the evening. Also can be seen that less energy is consumed around 2 o'clock in the afternoon. According to Menezes et al. (2014), the share of energy demand for computers is 25%, during lunchtime the computers are on standby mode. This is why the energy consumption decreased at lunchtime with around 25%. (Menezes et al., 2014; Rafsanjani, Ahm & Eskridge, 2018).

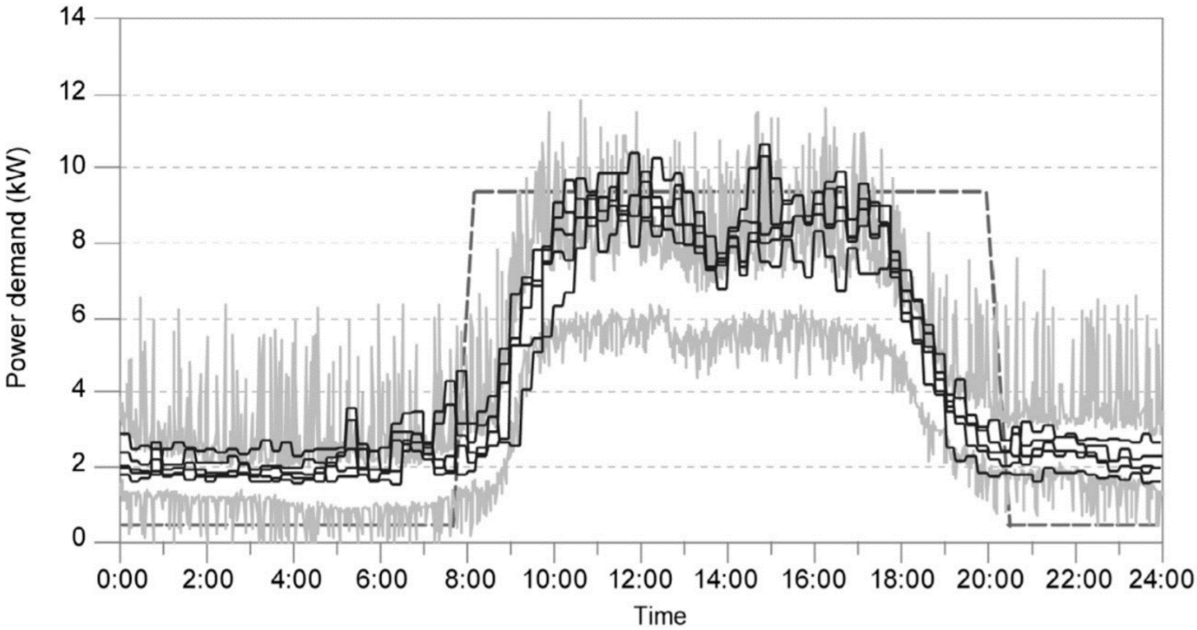


Figure 11. Predicted and metered weekday power demand profile of small office buildings (Menezes et al., 2014)

2.2.2. Influencing factors on the energy consumption of commercial buildings

Even as turning on or off computers, there are also other factors influencing the energy consumption of commercial buildings. According to Lindberg, Korpi & Vinha (2008), also weather factors have an influence on the energy use of a building, such factors are outside temperature and amount of sunlight. It is expected that more energy is consumed in winter, because the outside temperature is lower and there is less amount of sunlight (Lindberg, Korpi & Vinha (2008).

A study of Paul et al. (2012) proved that there are four main subjects influencing the energy demand of industrial and commercial buildings. These factors are (1) infrastructure; (2) building specific; (3) social, cultural and peer influence and (4) environmental concerns and attitudes, see also figure 12 (Paul et al., 2012). The infrastructure factors contains the type of the building, the insulation level, the number of floors, the building size and the age of the building. The building specific factors contains the work duration, type of industry, base consumption, equipment used, number of thermostats and number of occupants. For the social, cultural and peer influence accounts, when providing feedback on the energy bill of consumers, the energy consumption decreases. This feedback is based on energy consumption from equal buildings and provided every quarter of the year. For the environmental concerns and attitudes, this depends on the behavior of the energy consumers. In the consumer is energy conscious and more environmental friendly, the energy consumption is reduced (Paul et al., 2012).

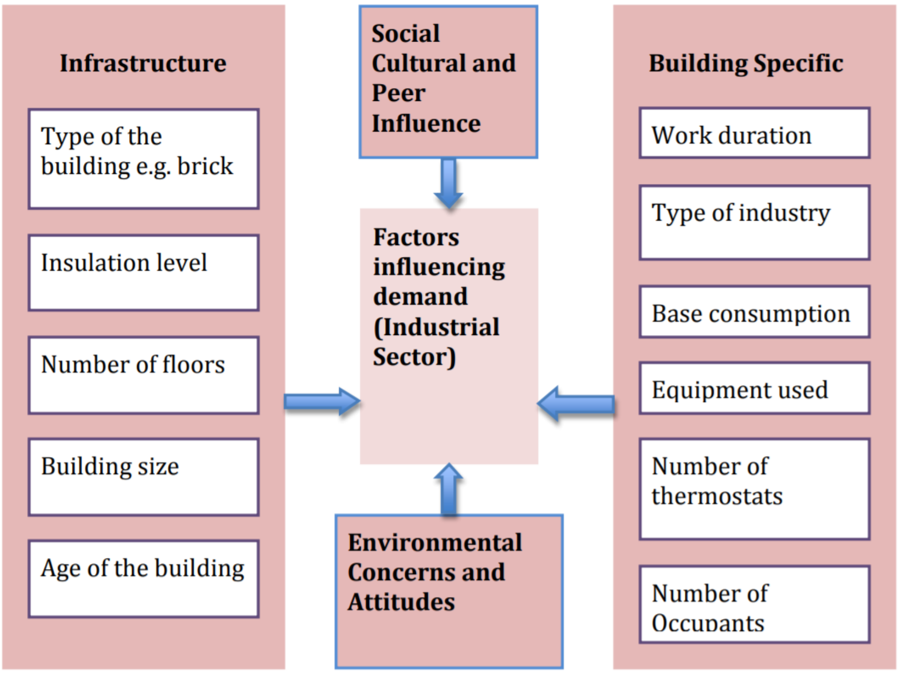


Figure 12. Influencing factors on the energy consumption behavior in the commercial/industrial sector (Paul et al, 2012)

2.3. User preferences

In the first two sections of this chapter, the energy efficient technologies, the energy consumption pattern and the influencing factors on the energy consumption are described and explained. In this section, the user preferences on the energy efficient technologies are identified. In addition, is described whether the environmental behavior of persons influence the energy consumption of a building. In this section also a difference is made between pupils and teachers.

2.3.1. Energy efficient technologies

User preferences on energy efficient technologies depends on different factors. Firstly, Guthridge (2010) proved that the consumers are less familiar with energy efficiency than they say. This study showed there is a misperception between understanding and saying to understand. Thereafter the price of the energy efficient technologies influences their choice to adopt. If the price of the energy efficient system is higher than the conventional system, most of the energy consumers are likely to adopt the conventional system. In addition, consumers are not inclined to change their behavior to optimize their energy consumption if it decreases their electricity bill.

2.3.2. Environmental behavior

As mentioned in subsection 2.2.2., also the environmental behavior of energy consumers influences the energy consumption. Consumers which are more energy conscious and environmental friendly are consume less energy (Paul et al., 2012). This is also proved by Sapci & Considine (2014).

According to Sütterlin & Siegrist (2014), the perception of the environmental behavior of persons show contradictions. In this study is proved that individual are likely to say they are energy conscious but instead they make choices that are not linked with energy-efficiency (Sütterlin & Siegrist, 2014).

2.3.3. Behavior of teachers and pupils

As mentioned in subsection 2.3.2., the environmental behavior influences the energy consumption. According to Wiernik, Ones & Dilchert (2013), the environmental behavior of individuals differs between particular age groups. This study proved that older individual are more likely to be engage with nature and avoid environmental harm than young individuals. Also elderly are more likely to conserve raw materials and natural resources. Assumed is that teachers are related to older individuals and pupils to younger individuals (Wiernik, Ones & Dilchert, 2013). Studies of Damerell, Howe & Milner-Gullard (2013) and Eilam & Trop (2012) proved that the environmental behavior of adults are contrasting the environmental behavior of children. Adults are more likely to be environmental friendly and energy conscious than children (Damerell, Howe & Milner-Gullard, 2013; Eilam & Trop, 2012).

According to Roose & Kerklaan (2012), energy and environmental awareness is responsibly high amongst pupils from 12-18 years old. Pupils are aware of the origin of energy, the energy consumption of applications and renewable energy. But despite the knowledge and awareness of energy, the behavior of pupils with respect to the environmental remains poor (Roose & Kerklaan, 2012).

2.4. Conclusion

In this section, the conclusions of the literature review are described. Firstly the conclusion on the energy efficient technologies are described. Secondly the conclusions on the energy consumption are specified. Finally, the user preference part is concluded.

2.4.1. Energy efficient technologies

2.4.1.1. General conclusion

In this chapter, various energy efficient technologies are introduced. For heating and cooling, heat emission systems are discussed, such as radiant wall and ceiling panels and thermally activated building systems. These systems can generate considerable energy savings in combination with low temperature heating and high temperature cooling. In addition, cogeneration and trigeneration are described, which are energy efficient heating sources. In comparison with traditional heating sources, these systems ensures less energy loss and can also generate additional electricity.

For the ventilation section, three energy efficient ventilation systems are discussed. Balanced heat recovery systems saves energy costs by extracting heat from exhausted air. Earth-air tube ventilation also extracts heat, but here the heat is extracted from the soil. Besides, Bauer Optimalisation ventilation technology is discussed. This technology provides energy savings, because this system uses no ventilation flow. It provides ventilation by means of a slow airstream. Due to a patent on this technology, only a few studies are conducted, therefore this technology has not been scientifically tested.

Also multiple renewable energy technologies are described. The renewable energy sources used for these technologies are geothermal, aerothermal, solar and wind energy. For geothermal and aerothermal energy technologies, heat pumps are used to extract the heat from the source and transfer it to a usable form of energy. Geothermal heat pumps, such as horizontal and vertical ground source heat pumps and groundwater heat pumps, benefit from the stable and uniform temperature of the energy source. This does not apply to aerothermal heat pumps. Heat pump water heaters, air to air and air to water heat pumps are aerothermal heat pumps and use the heat of the ambient air. Therefore, these systems are 70% less efficient in cold temperature climates.

Solar energy is the most commonly used renewable energy source. Solar energy is captured and transferred into electricity by photovoltaic cells. Solar energy technologies, such as photovoltaic panels, photovoltaic glazing and solar water heaters, are implemented with these photovoltaic cells. Photovoltaic panels are panels placed on the roof or façade of a building to capture electricity. Photovoltaic glazing is also used to capture electricity, but here the photovoltaics are semi-transparent and placed into the glass of a window. Solar water heaters uses solar energy to heat water for hot water and heating purposes. In addition, also wind energy can be used as renewable energy source for buildings. Roof-mounted or free-standing micro-wind turbines uses wind energy for electricity generation. These turbines are mainly placed in rural areas, because of higher efficiency and noise generation.

The technologies for energy storage discussed in this research are thermal energy storage, battery energy storage and smart grids. Thermal energy storage systems uses cold and hot boilers to store generated electricity. This system is less suitable for electricity generated by solar and wind energy, in comparison with battery energy storage. Battery energy storage systems store electricity mainly by means of lithium ion batteries. Due to these batteries, battery energy storage is less sustainable as thermal energy storage. Besides, also smart grids are used to store electricity. This is a network connected to electricity generators and consumers. Within a smart grid, electricity generated in one building can be consumed by another.

In the fifth section, three building automation technologies are specified: automatic lighting, automatic sun blinds and automatic daylight control. Automatic lighting and automatic daylight control directly result in energy savings for lighting. While automatic sun blinds provides less energy costs for cooling systems, by blocking heat from the sun automatically when the sun is shining bright.

2.4.1.2. Technologies applicable in school buildings

In the literature review, multiple energy efficient technologies are investigated. Advantages and disadvantages are explained. Moreover, the comments/requirements to apply these technologies in school buildings in the Netherlands are described in the previous section. The applicability and the requirements are presented schematically in table 2 and 3. Table 2 shows the requirements for implementation in new school buildings and table 3 shows the requirements for existing school buildings. These requirements describe whether it can be technically applied.

Table 2. Applicability of energy-efficient technologies in new school buildings

Technology	*Applicable?*	*Comment/requirement*
<u>Heating/cooling</u>		
Radiant ceiling/wall panels	Yes	
Thermally activated building systems	Yes	High thermal insulation is required Extra attention to the building design
Low temperature heating	Yes	High thermal insulation is required
High temperature cooling	Yes	High thermal insulation is required
Cogeneration	Yes	
Trigeneration	Yes	
<u>Ventilation</u>		
Balanced heat recovery systems	Yes	High thermal insulation is required
Earth-air tube ventilation	Yes	Large site is required
Bauer Optimalisation	No	Limited scientific research is done
<u>Renewable energy</u>		
Horizontal ground source heat pump	Yes	Large site is required
Vertical ground source heat pump	Yes	Not applicable in areas with groundwater protection
Groundwater heat pump	Yes	Not applicable in areas with groundwater protection Aquifer is required
Air to air heat pump	Yes	Less efficient in the Netherlands
Air to water heat pump	Yes	Less efficient in the Netherlands
Heat pump water heater	Yes	Not applicable for high demand
Photovoltaic panels	*	
Photovoltaic glazing	*	Extra attention to the building design
Solar water heater	Yes	Large storage tank is required Less efficient in the Netherlands
Micro-wind turbine	No	High levels of noise generation Less efficient in urban areas
<u>Energy storage</u>		
Thermal energy storage	Yes	Mostly for high consumption
Battery energy storage	Yes	
Smart grid	Yes	Available grid is required
<u>Building automation</u>		
Automatic lighting	Yes	
Automatic sun blinds	Yes	
Automatic daylight control	Yes	

** Determined in chapter 3, based on the school building's energy consumption pattern*

Table 3. Applicability of energy-efficient technologies in existing school buildings

Technology	*Applicable?*	*Comment/requirement*
Heating/cooling		
Radiant ceiling/wall panels	Yes	
Thermally activated building systems	No	Not applicable in renovation projects
Low temperature heating	Yes	High thermal insulation is required
		Difficult to apply in renovation projects in combination with convective heating systems
High temperature cooling	Yes	High thermal insulation is required
		Difficult to apply in renovation projects in combination with convective cooling systems
Cogeneration	Yes	
Trigeneration	Yes	
Ventilation		
Balanced heat recovery systems	Yes	High thermal insulation is required
Earth-air tube ventilation	Yes	Large site is required
Bauer Optimalisation	No	Limited scientific research is done
Renewable energy		
Horizontal ground source heat pump	Yes	Large site is required
Vertical ground source heat pump	Yes	Not applicable in areas with groundwater protection
Groundwater heat pump	Yes	Not applicable in areas with groundwater protection
		Aquifer is required
Air to air heat pump	Yes	Less efficient in the Netherlands
Air to water heat pump	Yes	Less efficient in the Netherlands
Heat pump water heater	Yes	Not applicable for high demand
Photovoltaic panels	*	
Photovoltaic glazing	*	Extra attention to the building design
Solar water heater	Yes	Large storage tank is required
		Less efficient in the Netherlands
Micro-wind turbine	No	High levels of noise generation
		Less efficient in urban areas
Energy storage		
Thermal energy storage	Yes	Mostly for high consumption
Battery energy storage	Yes	
Smart grid	Yes	Available grid is required
Building automation		
Automatic lighting	Yes	
Automatic sun blinds	Yes	
Automatic daylight control	Yes	

** Determined in chapter 3, based on the school building's energy consumption pattern*

2.4.2. Energy consumption

Commercial buildings consume the most energy between 8 o'clock in the morning and 8 o'clock in the evening. In these buildings, a remarkable decrease in the energy consumption can be seen during lunchtime. This is due to putting the computers on standby during lunch. Also other factors are influencing the energy consumption, such as weather factors, infrastructure of the buildings and building specific factors. Also social, cultural and peer influence and environmental concerns and attitudes are influencing the energy consumption of buildings.

2.4.3. User preferences

The user preferences on the energy efficient technologies is mainly based on the price of implementing the technology. If the price of a conventional system is lower, energy consumers are likely to adopt the conventional system. In addition, the user preferences on the energy efficient technologies are based on the environmental behavior of the individuals. Older individuals are more likely to be environmental friendly and energy conscious, in comparison with children.

2.5. Limitations

A limitation on the literature study is that there are more energy efficient technologies, which are not described in this chapter. The technologies described in this chapter are the most important and used technologies for school buildings based on the literature. Besides, the implementation of the energy efficient technologies in school buildings is determined technically based. This provision does not take account of financial assumptions.

The Bauer Optimisation ventilation technology is not further investigated because this technology is not scientifically reviewed. In the future, it could be that more information about this technology is published.

More extensive research must be conducted on the technologies defined as 'not very efficient in the Netherlands' in subsection 2.4.1.2. These technologies are defined in the literature as efficient in warm temperature climates. To give insight in the efficiency of these technologies in the Netherlands more extensive research must be conducted.

3. ENERGY CONSUMPTION PATTERN

To investigate if the energy efficient technologies, described in the previous chapter, can be implemented in school buildings, the energy consumption pattern of school buildings is determined. The energy consumption pattern is derived from ten school buildings, of which six primary schools and four secondary schools. These ten schools buildings are selected due to their smart energy measurement system. With the aid of this smart energy system, the energy consumption of these schools can be monitored.

This chapter contains the energy consumption pattern of ten school buildings in the Netherlands. First, the cases are described. Then, the energy consumption patterns of the school buildings are displayed and specified. After that, these patterns are used to figure out if solar energy is useful for implementation in school buildings. Thereafter is determined, which energy efficient technologies can be implemented in the ten cases, to upgrade the level of energy efficiency. Finally, the conclusion and discussion are described.

3.1. Cases

The school buildings used for monitoring energy consumption are primary schools with a floor area varying from 1,157 m² to 2,327 m² and secondary schools with floor areas from 4,328 m² to 9,457 m², see table 4 below. For the primary schools the amount of pupils varies between 196 and 453. The amount of pupils on the secondary schools vary from 228 to 1500. School 9 has a much larger area per pupil, because this school is a practice school. Therefore, this school contains many practical rooms with machines, which ensures that the area per pupil is larger on this school than on the other schools. This school also has two building layers, this also applies to the six primary schools. The other three secondary schools have three building layers. Besides, also the roof areas are shown in table 4, this is relevant to determine if there can be implemented with (more) photovoltaic (PV) panels. This determination is discussed in section 3.3.

Table 4. School buildings: school types, floor area and amount of pupils

School	*School type*	*Floor area (m²)*	*Amount of pupils (2016/2017)*	*Area / pupil (m²)*	*Building layers*	*Roof area (m²)*
School 1	Primary education	1,157	250	4.6	2	352
School 2	Primary education	2,327	389	5.9	2	1,584
School 3	Primary education	3,596	453	7.9	2	1,429
School 4	Primary education	1,735	293	5.9	2	1,249
School 5	Primary education	1,669	196	8.5	2	880
School 6	Primary education	1,485	209	7.1	2	893
School 7	Secondary education	9,457	1,155	8.1	3	3,664
School 8	Secondary education	6,677	1,500	4.4	3	3,673
School 9	Secondary education	4,328	228	18.9	2	2,158
School 10	Secondary education	6,975	1,089	6.4	3	2,325

In addition to the general characteristics, also the (thermal) building characteristics of these ten schools are described, see table 5. The year of construction, the R-values and the U-values are shown in table 5. The R-value is the thermal resistance of the building components. The higher the R-value, the better the building component is insulated. The thermal resistance must meet the requirements of the Dutch Building Regulations (in Dutch: Bouwbesluit) (Bouwbesluit, n.d.). On January 1st, 2015, the requirements that relates to the building envelope has been tightened. After the introduction of this revised requirement, the façade must have a thermal resistance (R-value) of 4.5 m²K/W. The R-value of the roof must be at least 6.0 m²K/W and the R-value of the floor must be at least 3.5 m²K/W, according to this revised requirements. Before tightening these requirements, the façade, roof and floor had to have a thermal resistance of minimum 3.5 m²K/W. The requirement for the floor still remains the same (Nieman, n.d.). The R-value of the facades, floors and roofs of the school buildings are shown in table 5 below. The revised requirements can be recognized in this table, the school buildings built in 2014 have lower R-values for facades and roofs. The requirement does not apply to renovation projects, as can be seen in the case of school 9. Besides the R-values, also the U-values of the school buildings are shown in table 5 below. The thermal resistance of windows is translated to the rate of heat loss (U-value). For the U-value applies, the lower the U-value, the more the window prevent heat loss (Bouwbesluit, n.d.). In table 5, also the energy performance coefficient (EPC) of the school buildings is included. The EPC value is an index value showing the energy efficiency of new buildings. The closer the value to zero, the better the energy efficiency of a building is. No data is available for school 9 & 10, the EPC value of these schools is estimated based on their year of construction (Arkesteijn, 2016).

Table 5. School buildings: (Thermal) building characteristics

School	*Year of construction*	*R-value façade (m^2K/W)*	*R-value floor (m^2K/W)*	*R-value roof (m^2K/W)*	*U-value windows (W/m^2K)*	*EPC value*
School 1	2016	4.5	3.5	6.0	1.6	0.79
School 2	2014	4.0	3.5	5.0	1.6	0.78
School 3	2014	3.5	3.5	5.0	1.6	0.71
School 4	2014	4.0	3.5	5.0	1.6	0.79
School 5	2016	4.5	3.5	6.0	1.65	0.20
School 6	2017	5.0	3.5	6.0	1.6	1.00
School 7	2014	4.4	3.5	5.0	2.1	0.80
School 8	2017	4.5	5.2	6.0	1.4	1.00
School 9	2017*	5.0	-**	2.0	1.1	1.40***
School 10	2008	-**	-**	-**	-**	1.40***

**: Year of renovation*
***: No data available*
****: Estimated based on the requirements (Bouwbesluit, n.d.)*

In addition to the thermal building characteristics, the school buildings also contain different installations for heating, cooling and ventilation. These installation characteristics are shown in table 6. For the heating systems, some school buildings applied energy efficient technologies, described in chapter 2 such a ground source heat pumps, air source heat pumps and low temperature heating. High efficiency boilers are applied in several school buildings. These are traditional heating systems, which transfers gas into heat for heating buildings (Huang et al., 1998). School 5, 6 and 9 use district heating as heating source for their school building. District heating uses waste heat from factories in industrial areas. For district heating, pipes must be laid in the ground from these industrial areas. Therefore, district heating is not available everywhere (Jangsten et al., 2017). School 7 is heated by an air handling unit. This heating system heats the building by means of heated air (Dey & Dong, 2016).

For the cooling systems implemented in the school buildings, energy efficient technologies are applied as well, such as ground source heat pumps, air source heat pumps and high temperature cooling. Moreover, school 2, 4 and 5 implemented electric chiller with compressor for cooling. This is a traditional cooling system, at which cooling is provided by means of a cold airstream or cold water through emission systems (Huang et al., 2018).

Table 6. School buildings: Installation types

School	*Heating system*	*Cooling system*	*Ventilation system*	*PV panels (m²)*
School 1	Ground/air source heat pump with high efficiency boiler	-	Balanced heat recovery system	145
School 2	High efficiency boiler with low temperature heating	Electric chiller with compressor	Mechanical ventilation (CO2 controlled)	0
School 3	Ground source heat pump with high efficiency boiler	Ground source heat pump with high temperature cooling	Balanced heat recovery system	0
School 4	High efficiency boiler with low temperature heating	Electric chiller with compressor	Mechanical ventilation (CO2 controlled)	0
School 5	Electric heat pump with district heating	Electric chiller with compressor	Mechanical ventilation (CO2 controlled)	437
School 6	District heating with low temperature heating	-	Mechanical ventilation (CO2 controlled)	46
School 7	Air handling unit	-	Natural ventilation	0
School 8	Air source heat pump with high efficiency boiler	Air source heat pump with high temperature cooling	Mechanical ventilation (CO2 controlled)	47
School 9	District heating	-	Mechanical ventilation (CO2 controlled)	0
School 10	*	*	*	600

**: No data available*

School 1 and 3 are ventilated by a balanced heat recovery system, this energy efficient ventilation technology is described in subsection 2.2.1. Most of the school buildings use a CO2 controlled mechanical ventilation system. This is, just as a balanced heat recovery system, a mechanically controlled ventilation system. The ventilation capacity is adjusted based on the level of CO2 in the building (Schibuola, Scarpa & Tambani, 2018). Unlike the other schools, school 7 uses a natural ventilation system. This system fulfills the ventilation need via ventilation grilles in the facades. As a result, the room is supplied with fresh outdoor air (Lei et al., 2017).

Five schools (school 1, 5, 6, 8 and 10) have photovoltaic (PV) panels on the roof of the school building, varying from 46 m² to 600 m², as shown in table 6. Photovoltaic panels are described in subsection 2.3.4.1.

3.2. Energy consumption pattern

In this section, the energy consumption pattern of ten schools is displayed. To give an accurate indication of this pattern, the energy consumption of these schools show a mean weekday spread over five months in the period from October 1, 2016 to September 30, 2017. The months November, January, March, June and September are displayed in this section, because these months have the least vacation days during the year. Table 7 below shows the Dutch school holiday in the school year 2016-2017. This is the reason October (autumn break), December (Christmas break), February (spring break), April/May (May holidays) and June/August (summer vacation), are not displayed in this section. By using the five months data, a clear energy pattern of these schools is determined.

Table 7. Dutch school holidays of school year 2016-2017 (Rijksoverheid, n.d.)

Kind of vacation	*Region*	*Holiday period*
Autumn break	North	October 14 to October 23, 2016
	Middle	October 14 to October 23, 2016
	South	October 21 to October 30, 2016
Christmas break	All regions	December 24, 2016 to January 8, 2017
Spring break	North	February 18 to February 26, 2017
	Middle	February 25 to March 5, 2017
	South	February 25 to March 5, 2017
May holidays*	All regions	April 22 to April 30, 2017
Summer vacation	North	July 22 to September 3, 2017
	Middle	July 8 to August 20, 2017
	South	July 15 to August 27, 2017

**: For the May holidays the schools are allowed to schedule an extra week of vacation*

Some of the school buildings have been applied with solar panels. This accounts for school 1, 5, 6, 8 and 10. The amount of solar panels differs between the schools. In table 8, the amount of solar panels per meter square is displayed.

Table 8. Amount of PV panels / m²

	Floor area (m²)	*PV panels (m²)*	*PV panels / m²*
School 1	1,157	145	0.125
School 5	1,669	437	0.262
School 6	1,485	46	0.031
School 8	6,677	47	0.007
School 10	6,975	600	0.086

In figure 13, the energy consumption patterns are displayed for the five above mentioned months. The energy consumption is displayed per meter square to equally compare the energy consumptions of the schools. The schools consume mainly the most energy between 7 o'clock in the morning and 8 o'clock in the evening. As can be seen, the schools consume the most energy in January in comparison with the other months. January is also the coldest of the five months with an average temperature from 0°C to 4°C.

The energy consumption of the schools normally have the shape of a bell curve. This does not account for the schools with solar panels. These schools consume most of the energy around 9 o'clock. After that moment, the energy consumption of these schools decreases. The energy consumption of school 8 does not show these results. This school has, in comparison with the other schools with solar panels, the lowest amount of solar panels per meter square, see table 8.

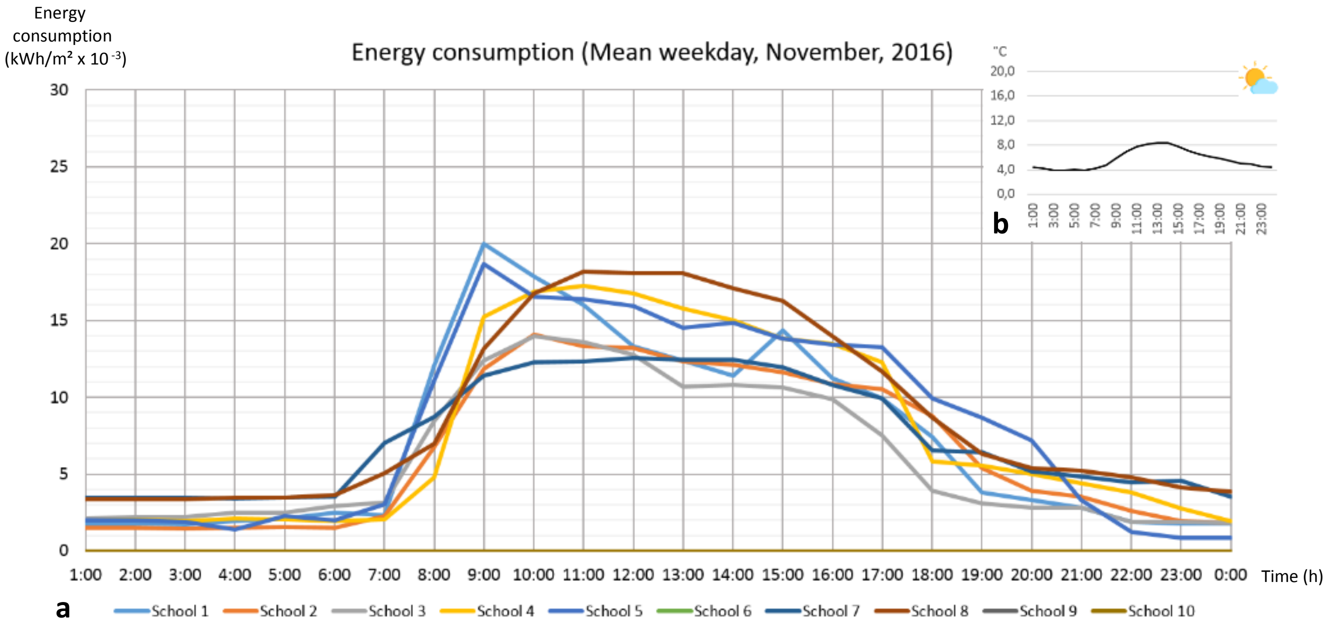
In the literature study is proved that commercial buildings have a 25% decrease in energy consumption during lunchtime. In figure 13 can be seen the energy consumption decreases a little around 1 o'clock in the afternoon, this decrease is lower than 25%. This can be due to the fact that in educational buildings the pupils mainly do not use laptops the whole day.

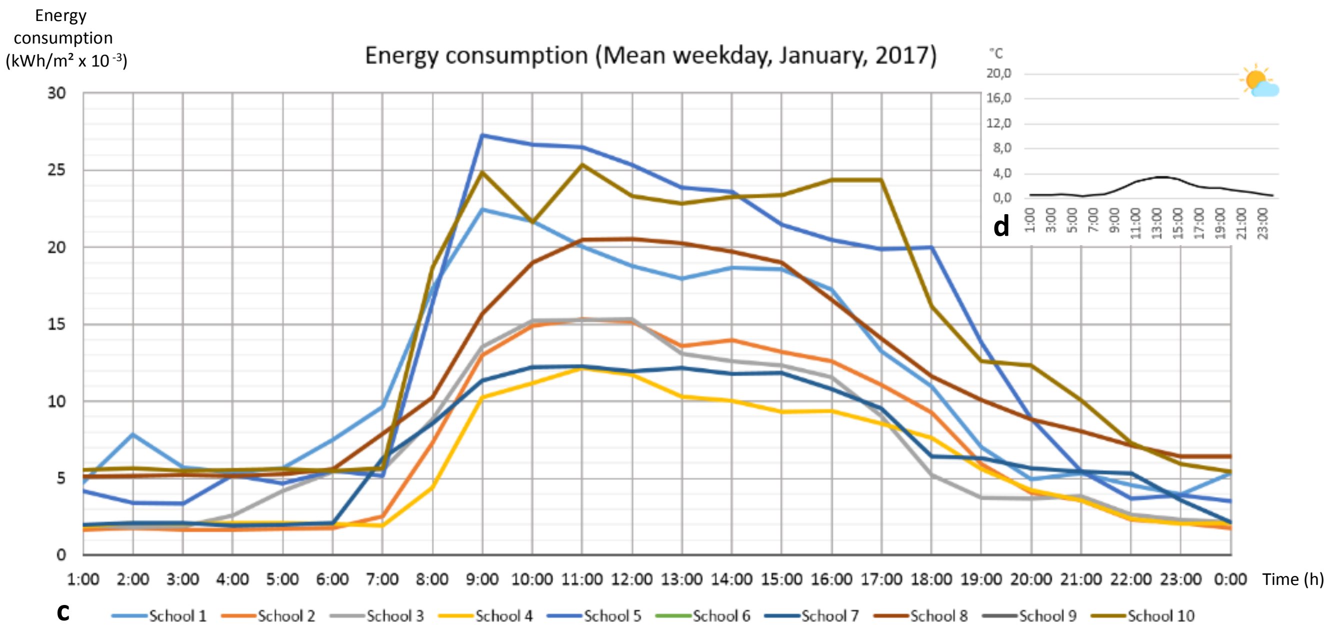
The energy consumption of the school buildings is displayed per meter square. School 9 has a high value of area per pupil, as can be seen in table 4. The energy consumption of this school is relatively low. If the energy consumption is displayed per pupil, the energy consumption of this school will increase remarkably.

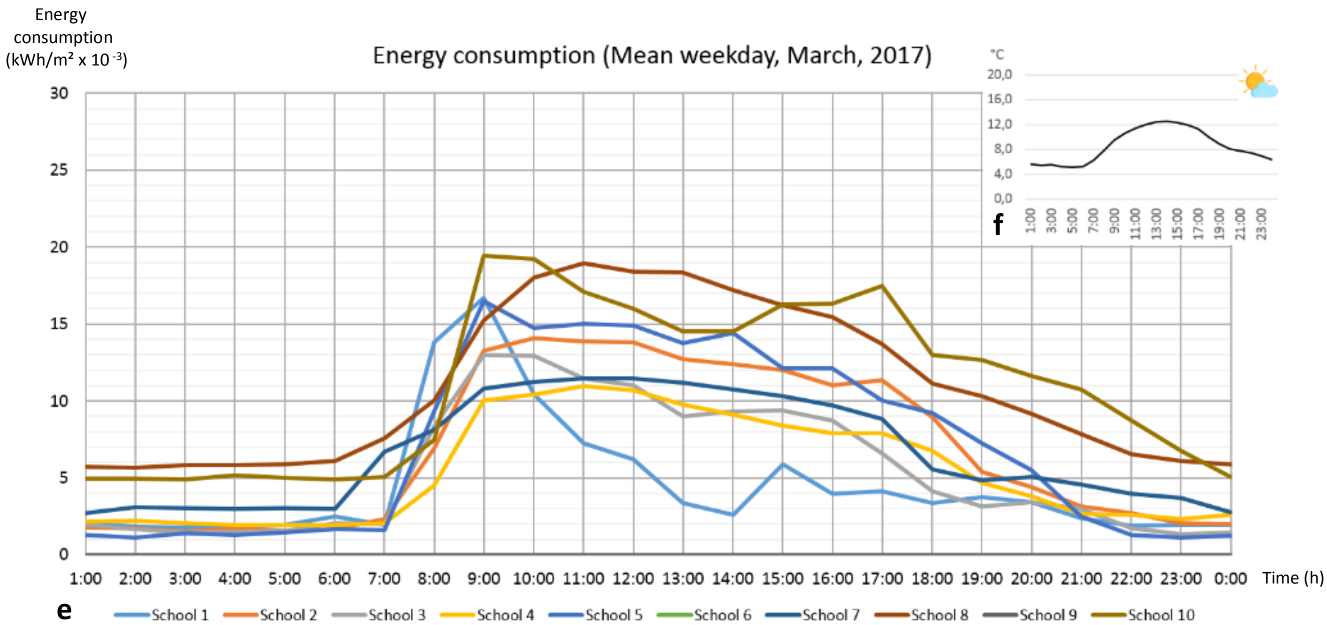
School 10 consumes in June and September more energy during the night. This can be due to the fact that some installations have been started during the night. It can also be that the lightning is turned on at a particular time.

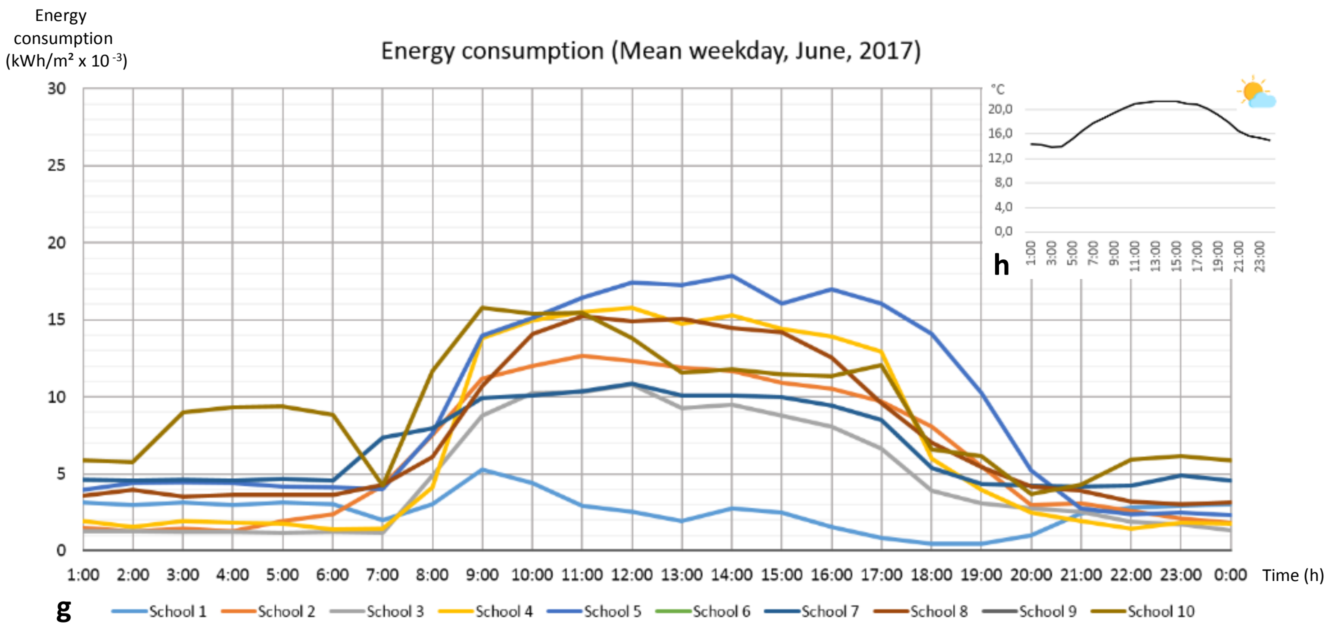
As can be seen in figure 13, the energy consumption in June is higher than in September. Also the mean temperature is higher in June. Schools with cooling systems implemented consume more energy in June, than schools without a cooling system. This can be the reason some schools consume more energy in June, in comparison with the energy consumption of September.

Finally, also is remarkable that school 1, 5 and 10 consume the most energy in January, while these schools have been implemented with the most amount of solar panels. There can be concluded that the solar panels are covered with snow, but the energy consumption pattern shows that the energy generated by solar panels is deducted.




Energy consumption (kWh/m² x 10⁻³)
Energy consumption (Mean weekday, January, 2017)
Time (h)
c
d
°C
School 1
School 2
School 3
School 4
School 5
School 6
School 7
School 8
School 9
School 10


Energy consumption (kWh/m² x 10⁻³)
Energy consumption (Mean weekday, March, 2017)
Time (h)
e
f
°C
School 1
School 2
School 3
School 4
School 5
School 6
School 7
School 8
School 9
School 10


Energy consumption (kWh/m² x 10⁻³)
Energy consumption (Mean weekday, June, 2017)
Time (h)
g
h
°C
School 1
School 2
School 3
School 4
School 5
School 6
School 7
School 8
School 9
School 10

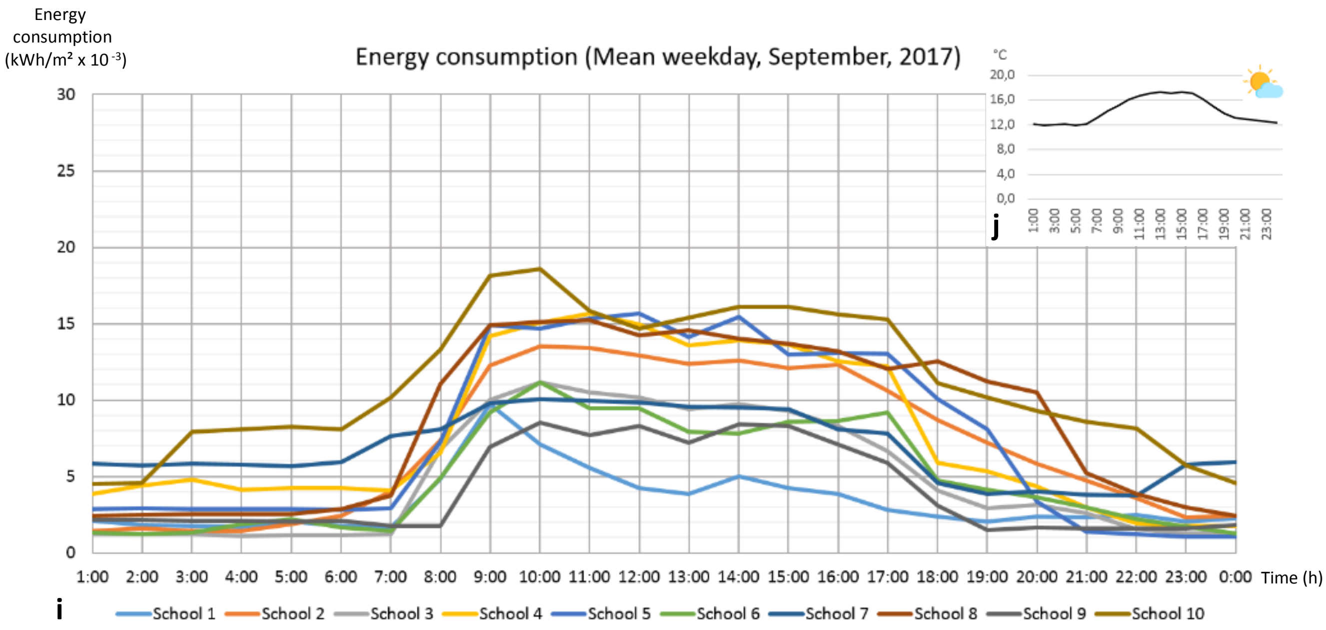


Figure 13. (a) Energy consumption in kWh/m² x 10 -3 on a mean weekday in November, 2016. (b) Temperature in °C on a mean weekday in November, 2016. (c) Energy consumption in kWh/m² x 10 $^{-3}$ on a mean weekday in January, 2017. (d) Temperature in °C on a mean weekday in January, 2017. (e) Energy consumption in kWh/m² x 10 $^{-3}$ on a mean weekday in March, 2017. (f) Temperature in °C on a mean weekday in March, 2017. (g) Energy consumption in kWh/m² x 10 $^{-3}$ on a mean weekday in June, 2017. (h) Temperature in °C on a mean weekday in June, 2017. (i) Energy consumption in kWh/m² x 10 $^{-3}$ on a mean weekday in September, 2017. (j) Temperature in °C on a mean weekday in September, 2017 (Temperature data is retrieved from KNMI)

3.3. Energy efficient technologies applicable

The ten school buildings discussed in the sections above, are implemented with energy efficient technologies, but can be applied with additional energy efficient technologies. The applicable technologies that can be implemented in existing school buildings are displayed in table 3 in chapter 2 of this research.

3.4.1. PV panels

In the previous section, the energy consumption patterns of the ten school buildings are displayed and described. The ten school buildings consume the most energy between 7 o'clock in the morning to 8 o'clock in the evening. According to Comello & Reichelstein (2017) the energy generation patterns of small and large solar installations generate energy between 6 o'clock in the morning and 6 o'clock in the evening. According to the energy consumption patterns of school buildings and the energy generation pattern of solar system, can be concluded that it is useful to implement solar systems in school buildings.

To indicate if (more) PV panels can be installed on the roof of the school buildings, multiple roof characteristics are shown in table 9. According to Mohajeri et al. (2018), the roof shape of the building determines the amount of solar panels that can be installed on the roof. A distinction is given to six roof shapes: flat, gable, hip, gambrel & mansard, cross/corner gable & hip and complex, see figure 14 (Mohajeri et al., 2018). In this figure, also the ratio of useful roof areas is included. In table 9, this ratio is multiplied by the roof area to determine the useful roof area for PV panels.

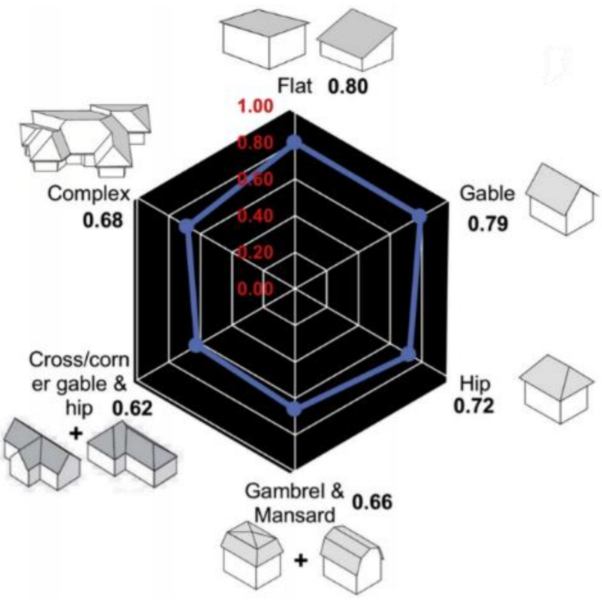


Figure 14. Roof shapes including ratio of useful roof areas (Mohajeri et al., 2018)

Table 9. School buildings: roof characteristics

	Roof area (m²)	*Roof shape*	*Ratio**	*Useful roof area for PV panels (m²)*	*PV panels (m²)*	*Building orientation***
School 1	352	Flat	0.80	281	145	North-east
School 2	1,584	Flat	0.80	1,267	0	North
School 3	1,429	Flat	0.80	1,143	0	North
School 4	1,249	Flat	0.80	999	0	North-east
School 5	880	Flat	0.80	704	437	North-west
School 6	893	Flat	0.80	714	46	North
School 7	3,664	Flat	0.80	2,931	0	North-east
School 8	3,673	Flat	0.80	2,938	47	North
School 9	2,158	Flat	0.80	1,726	0	North-west
School 10	2,325	Flat	0.80	1,860	600	North-west

**: The ratios are retrieved from Mohajeri et al. (2018)*
***: The building orientation is based on the direction of the longest side of the building*

All school buildings used in this research have a flat roof shape, see table 9 above. This is the most optimal shape for PV panels, according to Mohajeri et al. (2018). Also the orientation of the school building is important for indicating the amount of solar panels. The building orientation of the ten schools are described in table 9. According to Sick & Erge (1996), the solar panels are the most effective if placed at an angle between 15° and 57°, see red circle in figure 15. The most optimal direction for solar panels is mentioned from south-east to south-west.

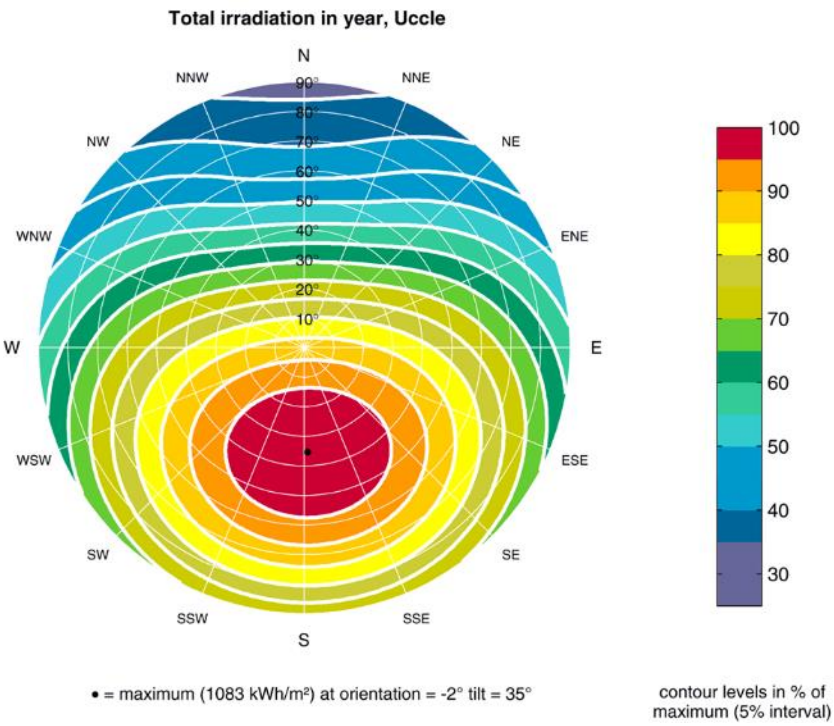


Figure 15. Slope and orientation of solar panels in Central Europe (Sick & Erge, 1996)

3.3.2. Heating/cooling

In table 6 in section 3.1., the heating and cooling systems already implemented in the school buildings are displayed. The heat pumps will be discussed as renewable energy technologies in subsection 3.4.3. School 2, 4 and 6 use low temperature heating. To implement low temperature heating and high temperature cooling in the other schools, the school buildings must not contain convective heating systems. According to the literature review, LTH or HTC combined with convective heating systems is not efficient. To make efficient use of low temperature heating and high temperature cooling, radiant heating systems must be also implemented. This combination of LTH/HTC with radiant wall and ceiling panels are a more energy efficient solution for the schools without low temperature heating. A requirement for LTH or HTC is a high thermal insulation of the buildings. Schools 1 to 8 contains a high thermal building insulation. Instead of the high efficiency boilers (in school 1, 3, 4, 6 and 8), it is more energy efficient to implement boiler systems with cogeneration and trigeneration. These boilers can also be implemented in the other school buildings.

3.3.3. Ventilation

In table 6 in section 3.1., the existing ventilation technologies are described. For implementing more energy efficient ventilation technologies, all school buildings can be applied with earth-air tube ventilation, if they are in the possession of a large site where the underground tubes can be laid in. School 1 and 3 already use a balanced heat recovery system for ventilation purposes. In the other schools this system can be implemented to be more energy efficient.

3.3.4. Renewable energy technologies

For renewable energy technologies, the technologies which uses solar energy as energy source, are useful to implement, according to subsection 3.3.1. For implementing solar glazing, extra attention must be paid on the building design. Solar water heaters can be implemented in school buildings in the Netherlands, but this system is more efficient in warm climates. Also for solar water heaters, it is only useful to implement if the building has room for a large water tank.

Other renewable energy technologies are geothermal and aerothermal heat pumps. Just like solar water heaters, aerothermal heat pumps are more efficient in warm climates. According to chapter 2, heat pump water heaters cannot deliver hot water for high demand, this must be taken into account when implementing this system. Geothermal heat pumps are efficient in the Netherlands, due to the stable ground temperature. School 1 and 3 have already implemented this system in their school building, also mentioned in table 6 in section 3.1. School 5 and 8 also have implemented heat pumps in the school buildings. To add more energy efficiency in the other school buildings, it is useful to implement a geothermal heat pump. Requirements for the vertical ground source heat pump and the groundwater heat pump are that this system cannot be implemented in groundwater protection areas, see table 3 in chapter 2. For implementing horizontal ground source heat pumps, a large site is required.

3.3.5. Energy storage and building automation

The energy storage systems described in chapter 2 of this research, can be implemented according to the literature. To implement thermal energy storage, there must be taken into account that this system is mostly used for high consumption. A requirement for combining the school building to a smart grid is that the smart grid must be available at this location. For building automation technologies, all the technologies can be implemented into the ten school buildings to upgrade the level of energy efficient, according to chapter 2.

3.4. Conclusion and discussion

3.4.1. Conclusion

In this chapter, the energy consumption of ten school buildings is described. These ten school buildings are primary and secondary schools and have various building features. The energy consumption pattern of the ten schools show that the school buildings mainly consume the most energy between 7 o'clock in the morning and 8 o'clock in the evening. Factors influencing the energy pattern are the outdoor temperature, the amount of pupils, the application of solar panels and the implementation of a cooling system. In the ten school buildings, additional energy efficient technologies can be implemented.

3.4.2. Discussion

In this chapter, only ten relatively new school buildings are included in the research. A more clear and realistic view of the energy consumption pattern can be displayed if more and also older school buildings are included. Besides, for the additional energy efficient technologies, further research must be done on applying these technologies in the ten school buildings.

4. ENERGY CONSUMPTION ANALYSIS

In chapter 2 is explained which energy efficient technologies are technically applicable in school buildings. Besides, the energy consumption pattern of the ten school buildings is determined in chapter 3 for the months November, January, March, June and September. Which variables influence the energy consumption of the school buildings has not yet been explained. In this chapter, an analysis is performed on the energy consumption of school buildings, to indicate the influencing factors.

In this chapter, first the data is described. Thereafter, the research approach is explained. In addition, a description of the dataset is provided. Besides the variables influencing the energy consumption of the ten school buildings are described. Finally, the conclusion and limitations are discussed.

4.1. Data

The data used in this analysis is retrieved from multiple references. In this section is described which references are used to gather the data for the energy consumption analysis.

4.1.1. Energy measurement system

To retrieve the energy consumption and energy production data of the schools, the energy measurement system of HEVO Construction management & consultancy is used. This energy measurement system monitors the energy consumption and production of several buildings. The energy consumption and production data is monitored per hour of the day. The energy measurement system only monitors the energy retrieved from the grid operator, this is excluding the energy used from solar panels.

4.1.2. General information of the school buildings

The general information of the school buildings is derived from a document management system of HEVO Construction management & consultancy. In this system the information of the school buildings is documented. This data consist of the technical characteristics of the buildings, such as amongst others surface area, year of construction/renovation, R-values of the façade, floor and roof and the type of installations for heating, cooling and ventilation.

4.1.3. General information of the schools

For the general information of the schools, the statutes of these schools are used. In the statutes can be found amongst others, the amount of pupils, time of education and the school holidays.

4.1.4. Weather data

Besides the information associated with the schools, the weather data is also included in this research. The literature study showed that the outside temperature and the amount of sunlight influence the energy consumption of buildings. This data is retrieved from 'Koninklijk Nederlands Meteorologisch Instituut' (KNMI). This institute monitors the weather data every hour of the day at multiple locations in the Netherlands.

4.1.5. Dataset

The energy measurement system of HEVO Construction management & consultancy monitored ten school buildings, also mentioned in chapter 3 of this research. The data of these school buildings are monitored over an amount of time. This amount is based on the available data. In table 10, can be derived what amount of data per school is implemented in the dataset.

For school 2, 3, 4 and 7 the energy consumption data is monitored for two years, from October 1, 2015 to September 30, 2017. One year of data is monitored of school 1, 5 and 8. School 10 is monitored from December 1, 2016 to September 30, 2017. School 6 and school 9 are monitored for a relatively short period, this is due to the fact these school buildings were completed recently before September 2017. The energy consumption of school 6 is monitored from September 1, 2017 to September 30, 2017. And the energy consumption of school 9 is monitored from August 14, 2017 to September 13, 2017.

Table 10. Amount of observations energy consumption data

	Period of monitoring	*Amount of days*	*Amount of observations*
School 1	October 1, 2016 – September 30, 2017	365	8.760
School 2	October 1, 2015 – September 30, 2017	731	17.544
School 3	October 1, 2015 – September 30, 2017	731	17.544
School 4	October 1, 2015 – September 30, 2017	731	17.544
School 5	October 1, 2016 – September 30, 2017	365	8.760
School 6	September 1, 2017 – September 30, 2017	30	720
School 7	October 1, 2015 – September 30, 2017	731	17.544
School 8	October 1, 2016 – September 30, 2017	365	8.760
School 9	August 14, 2017 – September 13, 2017	31	744
School 10	December 1, 2016 – September 30, 2017	304	7.296

As can be seen in table 10, the dataset in this analysis consists of ten groups with a varying amount of observations. This is called a panel dataset. Panel data represents a multidimensional dataset, namely multiple observations of multiple variables at different times. This means that characteristics of several people or institutions are observed at several moments in time (Greene, 2013). The dataset in this analysis is unbalanced, because the amount of observations vary between the groups. The dataset is therefore called an unbalanced panel dataset (Greene, 2013).

4.2. Research approach

In a panel dataset, problems such as heteroscedasticity and cross-correlation can occur, because many observations can have the same value. Each school has characteristics which do not vary over time, for example the year of construction. For each observation of one school, this variable has the same value. For this variable, the data is not variated equally, this can cause the problems when estimating a model. To handle panel data, a panel data regression model is a commonly used method (NUI Galway, n.d.; Torres-Reyna, 2007).

Panel data regression has two approaches, the fixed effects model and the random effects model. The fixed effects model determines the relationship between the dependent and the independent variables within a group. The group can have their own individual characteristics. The random effects model determines, unlike the fixed effects model, if the variation across groups is random and uncorrelated with the dependent and independent variables. Besides, the fixed effects model analyzes the data as a full population of possible groups and in the random effects model the data is a random sample of the population (Kreft & De Leeuw, 1998; Newsom, 2017; Snijders, 2005; Torres-Reyna, 2007). In this dataset, the groups have their own individual characteristics and can be seen as a population of possible groups, because the school buildings have their own features which can influence the energy consumption (dependent variable).

A drawback of estimating panel data is that the research must be spread over an amount of time to acquire the data. So, acquiring the data takes a lot of time. An advantage of analyzing panel data is also causality can be proved in comparison with a cross-sectional analysis. (Baltagi, 2005).

To analyze the panel data by means of the panel data regression model, the following formula is used (Torres-Reyna, 2007):

$$Y_{ij} = \beta_0 + \beta_1 X_{1,ij} + \beta_2 X_{2,ij} + \ldots + \beta_n X_{n,ij} + \varepsilon_{ij} \qquad (4.1)$$

Y_{ij}	=	Dependent variable (for i cases within j groups)
β_n	=	Coefficient for the independent variables
$X_{n,ij}$	=	Independent variables (for i cases within j groups)
ε_{ij}	=	Random error term (for i cases within j groups)

In the model, the structure of the dataset must be indicated. In this formula this is done by specify a group with j and the cases with i. The dependent variable Y_{ij} in this analysis is the energy consumption of the schools. The independent variables X_n are the variables influencing the energy consumption and are specified in the next section of this chapter.

If the dataset only exist of one independent variable, the equation for the fixed effects model is (Torres-Reyna, 2007):

$$Y_{ij} = \beta_1 X_{ij} + \alpha_j + \varepsilon_{ij} \qquad (4.2)$$

Y_{ij}	=	Dependent variable (for i cases within j groups)
β_n	=	Coefficient for the independent variable
$X_{n,ij}$	=	Independent variable (for i cases within j groups)
α_j	=	Separate intercept for each group j
ε_{ij}	=	Random error term (for i cases within j groups)

In the fixed effects model the within group variation can be determined with the separate intercept α_j for each group. In this analysis, multiple independent variables are included. The equation for the fixed effects model becomes:

$$Y_{ij} = \beta_1 X_{1,ij} + \beta_2 X_{2,ij} + \ldots + \beta_n X_{n,ij} + \alpha_j + \varepsilon_{ij} \qquad (4.3)$$

Y_{ij}	=	Dependent variable (for i cases within j groups)
β_n	=	Coefficient for the independent variables
$X_{n,ij}$	=	Independent variables (for i cases within j groups)
α_j	=	Separate intercept for each group j
ε_{ij}	=	Random error term (for i cases within j groups)

Some variables associated with the schools have no within group variation, because these variables have the same value for each school, these variables are called fixed parameters. For example, the type of installation does not vary over time, because the school has the same installation over the whole monitoring period. This variable is thus a fixed parameter and is excluded in the fixed effects model. Because this variable has no variation within the group, the fixed effect model cannot estimate a value.

4.3. Data description

In this section the data of this analysis is described and determined. In the first section is described which references are used to retrieved the data. In this section will be explained which variables are included in the energy consumption analysis. This section is separated in two parts, first the dependent variable is discussed and then the independent variables are described.

4.3.1. Dependent variable

The dependent variable in this analysis is the energy consumption of school buildings. This variable is monitored in ten school buildings with different surface areas. To implement the variables in the dataset in an equal way, the energy consumption is divided by the surface area of the school building. The energy consumption is displayed in kWh per meter square x 10^{-3} in this analysis.

The energy consumption is measured from zero up to around 60 kWh/m² x 10^{-3}. Due to multiple values between zero and 1, this dependent variable is not normally distributed. With a natural log-transformation, the variable will be normally distributed. A problem with a natural log-transformation are the zero values. The natural logarithm of zero is infinity and this value cannot be analyzed. To take into account the zero values, these values are transformed into 0.00001 (Feng et al., 2014; Torrent, 1978). Now the natural log-transformed energy consumption is measured from -11.51 up to 4.03.

4.3.2. Independent variables

The value of the dependent variable depend on the values of the independent variables in analyses. The independent variables are derived from the references mentioned in the first section of this chapter. Some of the independent variables in the analysis are effect coded to analyze the variables as predictors in the regression model (Te Grotenhuis et al., 2017). Effect coding uses 1's, 0's and -1's. The principle of effect coding is displayed in table 11 for 2, 3 and 4 attribute levels. With effect coding, the coefficients of the level that is not estimated in the model is derived by multiplying the sum of the other levels by -1. In this way, the last level of the attribute serves as a base.

Table 11. The principle of effect coding for 2, 3 and 4 attribute levels

Attribute level	*A1*
Level 1	1
Level 2 (base)	-1

Attribute level	*A1*	*A2*
Level 1	1	0
Level 2	0	1
Level 3 (base)	-1	-1

Attribute level	*A1*	*A2*	*A3*
Level 1	1	0	0
Level 2	0	1	0
Level 3	0	0	1
Level 4 (base)	-1	-1	-1

The energy consumption data is monitored per hour of the day. To analyze if the time of the day, day of the week and season of the year have an influence on the energy consumption of school building, these variables are included in the model. For the season of the year, spring, summer, autumn and winter are included. For the day of the week, all the days of the week are included. And the time of the day is separated in four parts, morning (from 6 am to 12 pm), afternoon (from 12 pm to 6 pm), evening (6 pm to 12 am) and night (12 am to 6 am)

(Mairs, 2012). These variables are effect coded in the analysis, the results of the effect coding are displayed in appendix B.

In this analysis also the education time and vacation time are included. The education time indicates the time when the pupils are being taught or not and the vacation time indicates if the pupils of the schools have a holiday period or not. These variables are also effect coded, the results of the effect coding are displayed in appendix B.

For the general information of the school buildings, multiple variables are included in the model, such as surface area, roof area, year of construction and amount of building layers. But also the thermal characteristics are included in the analysis. The R-value of the façade, floor and roof, the U-value of the windows and the EPC value characterize the thermal building envelope of the school buildings. The values of these variables can be obtained in section 3.1.

Besides, also the type of installations for heating, cooling and ventilation are included in the model. For heating systems, multiple combination are included in the analysis, such as heat pump with high efficiency boiler, high efficiency boiler with LTH, heat pump with district heating, district heating with LTH, air handling unit and district heating. For cooling systems, three types are included, electric chiller with compressor, ground source heat pump with HTC, air source heat pump with HTC and no cooling system implemented. For the ventilation systems, balanced heat recovery systems, mechanical ventilation and natural ventilation are included in the analysis. The variables are effect coded to analyze the variables as predictors. The results of effect coding for these variables are displayed in appendix B.

The general information of the school buildings also covers the amount of photovoltaic (PV) panels. This variable is included in the analysis and the values for the amount of PV panels can be obtained in section 3.1.

The weather data of KNMI is also included in the analysis. The outside temperature per hour of the day and the amount of sunshine per 10 minutes of an hour are included.

To make sure the independent variables are not correlated with other independent variables, a correlation analysis is performed. In appendix C, the first correlation matrix can be obtained. If two independent variables have a strong correlation, the variables must be combined or excluded from the dataset. Table 12 show the results of the correlation analysis.

As can be seen in table 12, the amount of pupils, surface area, building layer and roof area are strong correlated. The amount of pupils and the surface area variables can be combined as area per pupil. The surface area is divided by the amount of pupils to gain the data for the area per pupil variable. The variables building layer and roof area are excluded in the analysis.

Table 12. Results of the first correlation analysis

Variable description	*Variable names*	*Correlation*
Vacation time	Va1	Little correlation
Education time	Ed1	Little correlation
Season of the year	Se1, Se2, Se3, Se4	Little correlation
Day of the week	Day1, Day2, Day3, Day4, Day5, Day6	Little correlation
Part of the day	Dp1, Dp2, Dp3	Little correlation
Amount of pupils	Pupil	Strong correlations with a.o. area, layer and rarea
Year of construction	Year	Correlations with r-values
Surface area	Area	Strong correlations with a.o. pupil, layer, rarea and heating systems
Building layers	Layer	Strong correlations with a.o. pupil, area and rarea
Surface area roof	Rarea	Strong correlations with a.o. pupil, layer and area
R-value façade	Fac	Little correlation
R-value floor	Flo	Little correlation
R-value roof	Roo	Little correlation
U-value window	Win	Strong correlations with a.o. heating systems
EPC value	EPC	Little correlation
Heating system	Heat1, Heat2, Heat3, Heat4, Heat5	Strong correlations with a.o. cooling systems and ventilations systems
Cooling system	Cool1, Cool2, Cool3	Strong correlations with a.o. heating systems and ventilations systems
Ventilation system	Vent1, Vent2	Strong correlations with a.o. heating systems and cooling systems
PV panels	PV	Little correlation
Outside temperature	Tem	Little correlation
Amount of sunlight	Sun	Little correlation

In table 12, can also be observed that the types of heating, cooling and ventilation systems are strong correlated. The school buildings used in this research have some installation combinations which often occur. Heat pump with high efficiency boiler is often combined with balanced heat recovery system and high efficiency boiler with LTH is often combined with mechanical ventilation (CO2 controlled). This causes the correlation between the installation variables. Type of cooling system is excluded in this analysis. The heating and ventilation variables are combined to the variable type of installation. In this variable also a level is included for none of the above levels, because of the missing value of one school. This variable consists now of six attribute levels which can be obtained in appendix B. Also the results of effect coding are displayed in the table in appendix B.

With the inclusion of the new variables area/pupil and type of installations, a second correlation analysis is conducted. The second correlation matrix can be obtained in appendix D. Table 13 show the results of the correlation analysis.

Table 13. Results of the second correlation analysis

Variable description	*Variable names*	*Correlation*
Vacation time	Va1	Little correlation
Education time	Ed1	Little correlation
Season of the year	Se1, Se2, Se3, Se4	Little correlation
Day of the week	Day1, Day2, Day3, Day4, Day5, Day6	Little correlation
Part of the day	Dp1, Dp2, Dp3	Little correlation
Area per pupil	Apup	Little correlation
R-value façade	Fac	Little correlation
R-value floor	Flo	Strong correlations with type of installations
R-value roof	Roo	Strong correlations with type of installations
U-value window	Win	Strong correlations with type of installations
EPC value	EPC	Strong correlations with type of installations
Type of installations	In1, In2, In3, In4, In5	Strong correlations with R-values, U-value and EPC-value
PV panels	PV	Little correlation
Outside temperature	Tem	Little correlation
Amount of sunlight	Sun	Little correlation

As can be seen in table 13, R-values of the floor and roof, U-value of the window, EPC value and the types of installations are strongly correlated. To prevent multicollinearity in the analysis, the R-values for the floor and roof and the U-value of the window are excluded. R-value of the façade have only little correlation, but this variable only characterize the façade of the building. The EPC value instead characterizes the whole building, and is, for this reason, included in the analysis instead of the R-value of the façade.

4.4. Results

In this section, the results of this analysis are presented. First the performance of the model is determined. Thereafter, the coefficients of the attributes are displayed and explained. Finally the conclusion and limitations are described.

4.4.1. Model performance

In regression analyses, the model performance is determined based on the coefficient of determination (r^2). This coefficient shows the proportion of variance in the dependent variable which is predicted by the independent variables. The r^2 ranges from 0 to 1. The higher the r^2 is, the better the data fits the estimated model. A model with a r^2 close to 1 shows that the data of this model is close to the regression line. In this case, there is less variance in the prediction of the dependent variable.

In this analysis, two model estimations are generated. First, a model is generated including the dependent variable without natural log-transformation. After that, a model is generated with the natural log-transformed dependent variable. For both the models, the coefficient of determination (r^2) is calculated, see appendix E. The r^2's of the models are displayed in table

14. The model without natural log-transformation (1) has a r^2 of 0.66. The model with natural log-transformation (2) has a r^2 of 0.33. Because this model has a natural log-transformed dependent variable, the coefficient of determination is calculated based on this dependent variable. To fairly compare results, it is better to determine the r^2 between the untransformed Y-values and the exponent of the predicted Y-values. Then the r^2 increases to 0.53.

Table 14. Coefficients of determination (r^2's)

		r^2
1	$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_nX_n + \varepsilon$	0.659423
2	$Ln(Y) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_nX_n + \varepsilon$	0.334824
3	$Exp(Ln(Y)) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_nX_n + \varepsilon$	0.526628

Normally, the model with the highest r^2 is the most reliable model. In this analysis, the natural log-transformed dependent variable has a normal distribution. The dependent variable without natural log-transformation is not normally distributed. This is the reason, the model with the natural log-transformed dependent variable is assumed to be the most reliable model.

4.4.2. Regression models

For this analysis, both models are estimated. The output of the model with the dependent variable without natural log-transformation can be obtained in appendix F. The output of the model with the natural log-transformed dependent variable can be obtained in appendix G. In table 15, the coefficients of both models are displayed. As can be seen, the coefficients of the models are measured on another scale. Because of this, the models cannot be compared on the weight of the values.

The constant term in regression analysis is defined as the mean of the dependent variable, when all the independent variables are zero. In the model with the dependent variable without natural log-transformation (model 1), the constant term is 9.21. In the model with the natural log-transformed dependent variable (model 2), the constant term is 3.38. The constant term in this model is lower, because the dependent variable is natural log-transformed.

For the effect coded variables, the base must be calculated by dividing the sum of the coefficients times -1. The bases are calculated for these variables and displayed in table 15.

For model 1, the education time is, the most influencing factor on the energy consumption of school buildings. In model 2, the EPC value is the most influencing factor on the energy consumption. It is remarkable both models do not show the same outcomes.

If the schools are educating pupils, more energy is used than if the school time is over. This is as expected, and also model 2 shows this result. In holiday periods, also less energy is consumed, in comparison with periods with normal weeks of school. This also accounts for model 2.

For the seasons of the year, both models show that when it is spring, the least energy is consumed. After spring, the most energy is consumed during the summer. As expected, in both models, winter is the season with the highest energy consumption.

For the days of the week, in model 1, on Mondays the most energy is consumed. In model 2 the most energy is consumed on Tuesdays. As expected, for both models, the least energy is used on Sundays.

For the part of the day, in model 2, in the mornings the most energy is consumed. In model 1 the most energy is consumed at afternoon. As expected, for both models, the least energy is used during the night.

In both models, the coefficients for the area per pupil have the same direction. In the models is proved, the higher the area per pupil, the more energy is consumed. For the EPC value applies in both models, that the higher the EPC value, the lower the energy consumption. This is remarkable, because buildings with a lower EPC value are more sustainable, then buildings with a high EPC value. In subsection 4.4.4., this contradiction will be further explained.

For the type of installations, a ground/air heat pump with high efficiency boiler combined with a balanced heat recovery system consume the least energy in both the models. These both systems are described as energy efficient in chapter 2 of this research. In model 1, an air handling unit in combination with natural ventilation system consume the most energy. These systems are not defined as energy efficient technologies in the literature study. These systems are less energy efficient than the other installation systems, these results are as expected. In model 2 the 'none of the above systems' choice consumes the most energy.

In the first model, the higher the amount of PV panels, the more energy is consumed. This is remarkable because PV panels produce energy and must decrease the energy consumption. In model 2 the opposite is proved. This seems to be a more realistic result. In subsection 4.4.4., the remarkable result of model 1 will be further explained.

For the outdoor temperature applies in both models as expected, that the higher the temperature, the less energy is consumed. For the amount of sunlight also applies in both models, the more sunlight, the less energy is consumed.

Table 15. Coefficients of the models: Y and Ln(Y)

X_n	*Variable*	*Coefficients*			
		Model 1: Y		*Model 2: Ln(Y)*	
Constant	Constant	9.21001	***	3.38480	***
Va1	Vacation time	-.52396	***	-.14503	***
(base)	*No vacation time*	*.52396*		*.14503*	
Ed1	Education time	3.98319	***	.58903	***
(base)	*No education time*	*-3.98319*		*-.58903*	
Se1	Spring	-.54757	***	-.11446	***
Se2	Summer	-.16235	***	-.04104	***
Se3	Autumn	.07791	***	.03024	***
(base)	*Winter*	*.63201*		*.12526*	
Day1	Monday	.97643	***	.23433	***
Day2	Tuesday	.94706	***	.26437	***
Day3	Wednesday	.82732	***	.23540	***
Day4	Thursday	.80121	***	.23061	***
Day5	Friday	.30305	***	.15734	***
Day6	Saturday	-1.86411	***	-.52672	***
(base)	*Sunday*	*-1.99096*		*-.59533*	
Dp1	Morning	1.31645	***	.20188	***
Dp2	Afternoon	1.65566	***	.11790	***
Dp3	Evening	-1.22296	***	-.10966	***
(base)	*Night*	*-1.74915*		*-.22296*	
Apup	Area / pupil	.18704	***	.11857	***
Epc	EPC value	-1.28444	***	-2.08833	***
In1	Ground/air heat pump with high efficiency boiler Balanced heat recovery system	-2.20615	***	-1.19369	***
In2	High efficiency boiler with LTH Mechanical ventilation (CO2 controlled)	-.83185	***	-.63374	***
In3	Central heating Mechanical ventilation (CO2 controlled)	-2.11263	***	-.77203	***
In4	Air handling unit Natural ventilation	3.40481	***	.00191	
In5	Air source heat pump with high efficiency boiler Mechanical ventilation (CO2 controlled)	1.62927	***	.61090	***
(base)	*None of the above*	*.11655*		*1.98665*	
Pv	Amount of PV panels	.00463	***	-.00256	***
Tem	Outside temperature	-.10781	***	-.02725	***
Sun	Amount of sunlight	-.04034	***	-.03248	***

4.4.3. Fixed effects models

In the fixed effects model the within group variation can be determined. The output of the model with the dependent variable without natural log-transformation can be obtained in appendix F. The output of the model with the natural log-transformed dependent variable can be obtained in appendix G. In table 16, the coefficients of the regression model and the fixed effects model of model 1 are displayed. The coefficients of model 2 are displayed in table 17.

As can be seen in both tables the coefficients of the regression model and the fixed effects model shows some differences, but these differences are negligibly small in both model 1 and model 2. There can be concluded that the variables in the fixed effects models have a negligibly little variation within the groups.

Table 16. Coefficients of the regression and fixed effects models: Y

X_n	Variable	*Coefficients*			
		Model 1: Y		*Fixed effects model*	
Va1	Vacation time	-.52396	***	-.52402	***
(base)	*No vacation time*	*.52396*		*.52402*	
Ed1	Education time	3.98319	***	3.98306	***
(base)	*No education time*	*-3.98319*		*-3.98306*	
Se1	Spring	-.54757	***	-.54762	***
Se2	Summer	-.16235	***	-.16223	***
Se3	Autumn	.07791	***	.07790	***
(base)	*Winter*	*.63201*		*.63195*	
Day1	Monday	.97643	***	.97644	***
Day2	Tuesday	.94706	***	.94708	***
Day3	Wednesday	.82732	***	.82733	***
Day4	Thursday	.80121	***	.80123	***
Day5	Friday	.30305	***	.30307	***
Day6	Saturday	-1.86411	***	-1.86414	***
(base)	*Sunday*	*-1.99096*		*-1.99101*	
Dp1	Morning	1.31645	***	1.31650	***
Dp2	Afternoon	1.65566	***	1.65560	***
Dp3	Evening	-1.22296	***	-1.22300	***
(base)	*Night*	*-1.74915*		*-1.74910*	
Apup	Area / pupil	.18704	***	Fixed parameter	
Epc	EPC value	-1.28444	***	Fixed parameter	
In1	Ground/air heat pump with high efficiency boiler Balanced heat recovery system	-2.20615	***	Fixed parameter	
In2	High efficiency boiler with LTH Mechanical ventilation (CO2 controlled)	-.83185	***	Fixed parameter	
In3	Central heating Mechanical ventilation (CO2 controlled)	-2.11263	***	Fixed parameter	
In4	Air handling unit Natural ventilation	3.40481		Fixed parameter	
In5	Air source heat pump with high efficiency boiler Mechanical ventilation (CO2 controlled)	1.62927	***	Fixed parameter	
(base)	*None of the above*	*.11655*		Fixed parameter	
Pv	Amount of PV panels	.00463	***	Fixed parameter	
Tem	Outside temperature	-.10781	***	-.10781	***
Sun	Amount of sunlight	-.04034	***	-.04033	***

Table 17. Coefficients of the regression and fixed effects models: Ln(Y)

X_n		*Coefficients*			
		Model 2: Ln(Y)		*Fixed effects model*	
Va1	Vacation time	-.14503	***	-.14512	***
(base)	*No vacation time*	*.14503*		.14503	
Ed1	Education time	.58903	***	.58880	***
(base)	*No education time*	*-.58903*		-.58880	
Se1	Spring	-.11446	***	-.11454	***
Se2	Summer	-.04104	***	-.04083	***
Se3	Autumn	.03024	***	.03021	***
(base)	*Winter*	*.12526*		*.12516*	
Day1	Monday	.23433	***	.23436	***
Day2	Tuesday	.26437	***	.26439	***
Day3	Wednesday	.23540	***	.23540	***
Day4	Thursday	.23061	***	.23063	***
Day5	Friday	.15734	***	.15737	***
Day6	Saturday	-.52672	***	-.52677	***
(base)	*Sunday*	*-.59533*		*-.59538*	
Dp1	Morning	.20188	***	.20197	***
Dp2	Afternoon	.11790	***	.11796	***
Dp3	Evening	-.10966	***	-.10973	***
(base)	*Night*	*-.22296*		*-.21020*	
Apup	Area / pupil	.11857	***	Fixed parameter	
Epc	EPC value	-2.08833	***	Fixed parameter	
In1	Ground/air heat pump with high efficiency boiler Balanced heat recovery system	-1.19369	***	Fixed parameter	
In2	High efficiency boiler with LTH Mechanical ventilation (CO2 controlled)	-.63374	***	Fixed parameter	
In3	Central heating Mechanical ventilation (CO2 controlled)	-.77203	***	Fixed parameter	
In4	Air handling unit Natural ventilation	.00191		Fixed parameter	
In5	Air source heat pump with high efficiency boiler Mechanical ventilation (CO2 controlled)	.61090	***	Fixed parameter	
(base)	*None of the above*	*1.98665*		*Fixed parameter*	
Pv	Amount of PV panels	-.00256	***	Fixed parameter	
Tem	Outside temperature	-.02725	***	-.02725	***
Sun	Amount of sunlight	-.03248	***	-.03248	***

In table 18, also the values of the separate intercept α_j of model 1 and 2 can be obtained. As can be seen is that group 7 has the highest group intercept in both models and is in this analysis the largest energy consumer. Group 6 has the lowest intercept value in model 1 and group 1 has the lowest value in model 2.

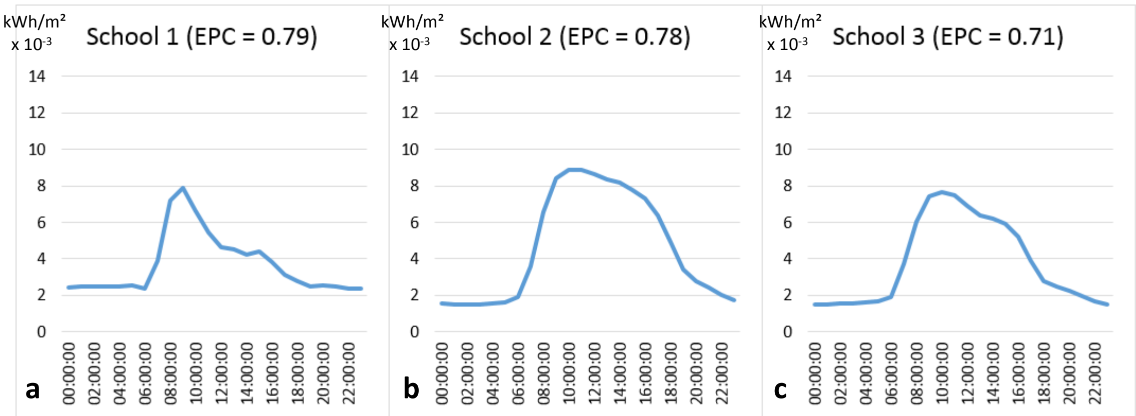
Table 18. *Separate intercept coefficients for each group for model Y and model Ln(Y)*

	Coefficients	
	Model 1: Y	*Model 2: Ln(Y)*
Group 1	7.52547	.71630
Group 2	8.46583	1.78061
Group 3	7.57764	1.65088
Group 4	8.49956	1.85345
Group 5	10.45921	2.08677
Group 6	7.35159	1.24204
Group 7	13.11908	2.68696
Group 8	10.60487	2.31447
Group 9	8.84719	1.93590
Group 10	11.50525	1.66974

4.4.4. Contradictions regarding the EPC value and the PV panels

In the model estimations, remarkable results are shown for EPC value and PV panels. In figure 16, the mean energy consumption of the monitoring period per school is displayed in kWh/m² x 10^{-3}. This is the mean energy consumption of all days of the week. Therefore these energy consumptions are lower than the patterns in chapter 3. In figure 16, also the EPC values of the school buildings are shown. For the energy performance coefficient applies, the lower the EPC value of a building, the more energy efficient the building is.

As can be seen in figure 16, school 5 has the lowest EPC value (0.2). The energy consumption of school 5 tend to be the highest of the ten schools, together with school 8 and school 10. School 9, which has an EPC value of 1.4, tend to have the lowest energy consumption. The disruption of the coefficients for EPC value proved in the regression model are probably caused by school 5 and school 9.



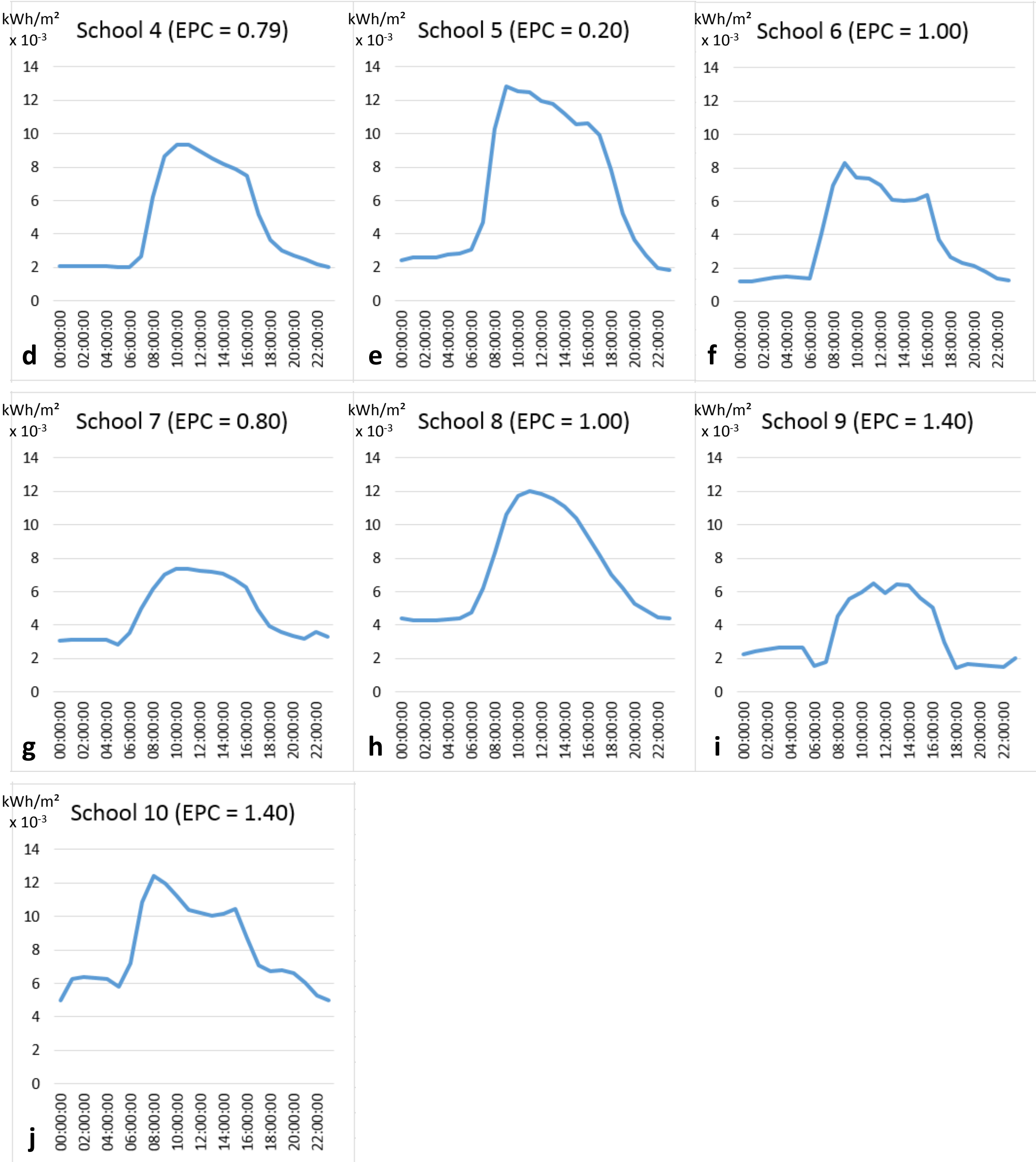


Figure 16. Mean energy consumption in kWh/m² & EPC values of: (a) School 1. (b) School 2. (c) School 3. (d) School 4. (e) School 5. (f) School 6. (g) School 7. (h) School 8. (i) School 9. (j) School 10.

In figure 17, the mean energy consumptions of the five schools applied with solar panels are displayed in kWh/m² x 10^{-3}. Also the amount of solar panels of these five school buildings are shown. As can be seen in figure 17, school 5 and school 10 have the highest amount of PV panels on the roof of the buildings, respectively 437 m² and 600 m². Also can be seen in figure 17, that these school buildings consume the most energy together with school 8. There can be assumed that less energy is consumed when solar panels are applied on the building. School 5 and school 10 have a relatively high amount of solar panels, but also have a high energy consumption. The contradiction of PV panels in the regression model is probably caused by school 5 and school 10.

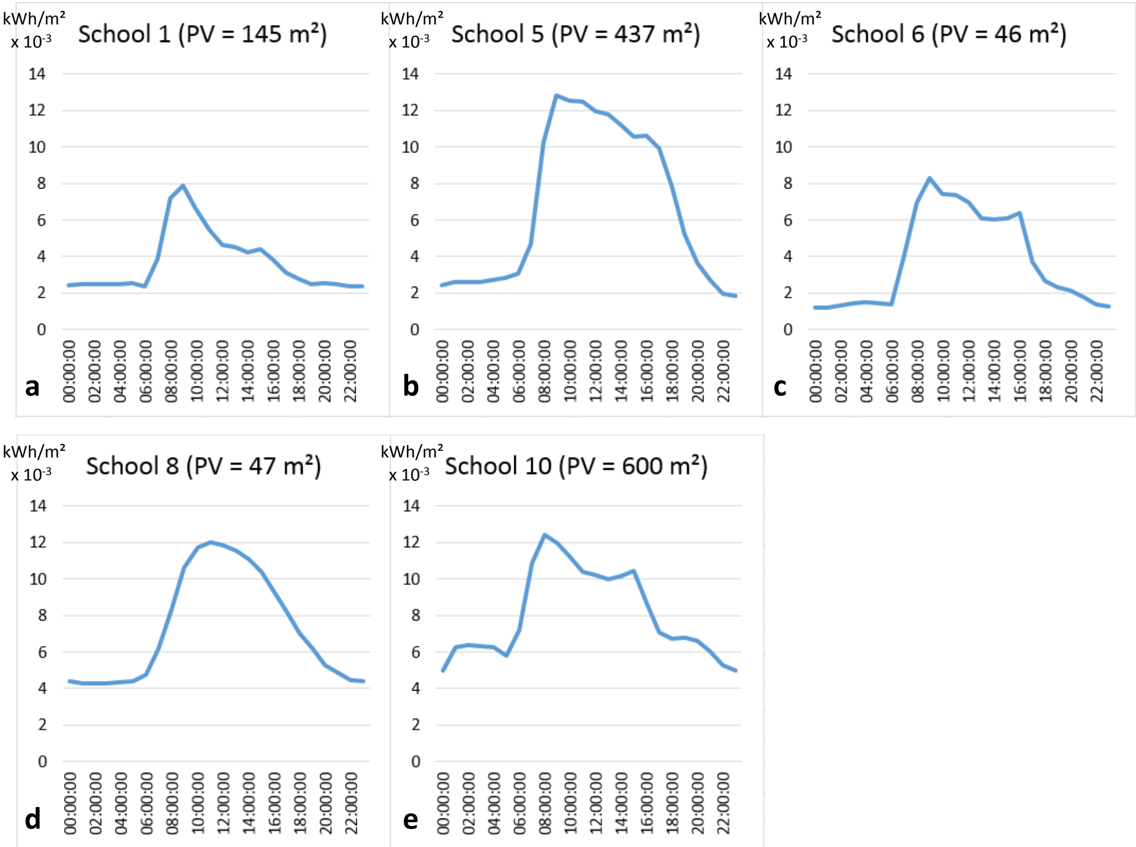
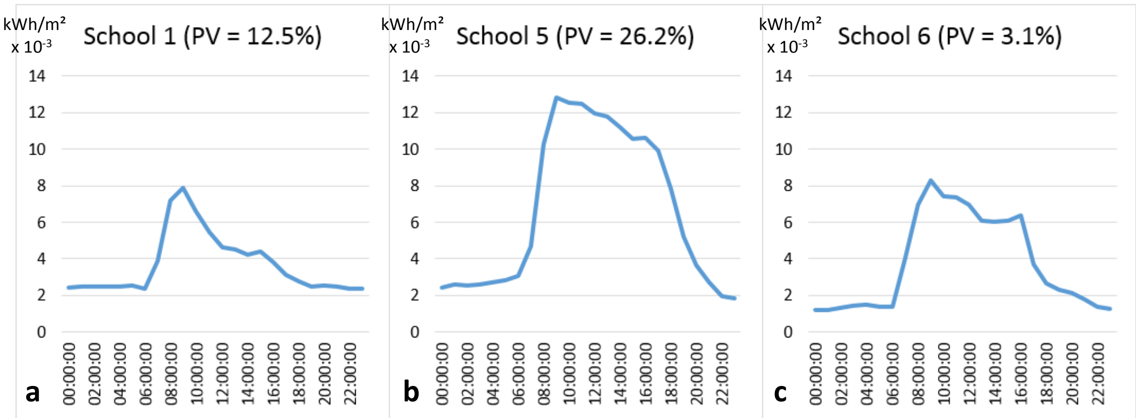


Figure 17. Mean energy consumption in kWh/m² & amount of PV panels of: (a) School 1. (b) School 5. (c) School 6. (d) School 8. (e) School 10.

In figure 18, the amount of PV panels is divided by the surface area of the school buildings to get the share of the PV panels. As can be seen in figure 18, school 5 has the highest share of PV panels (26.2%). This school also consumes the most energy, together with school 8 and school 10. Implementing the share of PV panels in the model would still cause contradictions, due to school 5.



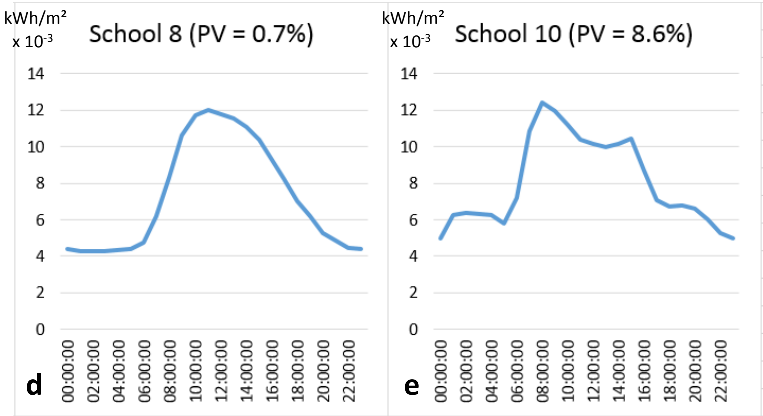


Figure 18. Mean energy consumption in kWh/m² & share of PV panels of: (a) School 1. (b) School 5. (c) School 6. (d) School 8. (e) School 10.

By excluding school 5 from the analysis, the sample size becomes too small to estimate a model. The dataset in this analysis includes a small sample of schools with limited variation in the independent variables. The independent variables are mutually correlated as well. This probably causes unexpected results in the estimated model. To improve the models, the energy consumption data of more school buildings is needed.

4.5. Conclusion and discussion

4.5.1 Conclusion

In this chapter, a panel data regression analysis is performed on the energy consumption data of school buildings. Besides, two fixed effects models are estimated to show the within group variation. The first model contains the energy consumption without log-transformation. The second model contain a natural log-transformed energy consumption, in this model the dependent variable is normally distributed.

Both models show different results in the model estimation. For model 1, the most influencing factor on the energy consumption is the education time. In model 2, the EPC value is the most important variable. As expected, during vacation time less energy is consumed and during education time more energy is consumed. During the winter, the most energy is consumed. Thereafter the most energy is consumed during autumn. The least energy is consumed during spring. In model 1, on Mondays the most energy is consumed, in model 2 the most energy is consumed on Tuesdays. As expected in both models, the least energy is consumed on Sundays.

For both models apply that the higher the area/pupil, the more energy is consumed. Regarding type of installation, a high efficiency boiler combined with a ground/air heat pump and a balanced heat recovery system consumes in both models the least energy. The most energy is consumed in model 1 with an air handling unit and natural ventilation. As expected, the higher the outside temperature and the higher the amount of sunlight, the less energy is consumed. The fixed effects model proved that there is only negligibly little within group variation.

The coefficient for EPC value is in both models negative, this means the higher the EPC value, the lower the energy consumption. This is strange because for the EPC value applies the lower the EPC value, the more energy efficient the building. Also remarkable is that the coefficient for PV panels in model 1 is positive. This means the more PV panels are implemented on the building, the higher the energy consumption. This is strange because PV panels generate energy and must therefore reduce the energy consumption. In model 2, the coefficient is negative. There is assumed that this contradiction is caused by school 5. Excluding school 5 from the model does not solve the problem as the sample of the schools becomes too small. Energy consumption data of more school buildings is needed to improve the model.

4.5.2. Discussion

Multiple variables are excluded in the analysis due to correlations. If a judgement must be made about the excluded variables, further research must be conducted. Also only 10 school buildings are used in this research, if more cases are investigated, more specific and extensive judgements can be made.

5. USER PREFERENCES

In chapter 2, the energy efficient technologies which are technically applicable in school buildings have been described. Also the energy consumption pattern is determined to indicate if solar energy can be used as energy generator for these buildings in chapter 3. In addition is explained in chapter 4 which variables are influencing the energy consumption of school buildings. The preferences of the school building users with regard to the new energy efficient technologies have not yet been discussed. In this chapter, the preferences of the school building users are investigated.

In this chapter, first the research approach is explained, including the research method and the design of the questionnaire. Thereafter, the data description and the results of this research analysis are described. Finally, all findings of this chapter are discussed in the conclusion.

5.1. Research approach

In this section, the research approach is described. First, the method of this research is discussed. Among others, the advantages and disadvantages of this method are discussed. Then, the questionnaire is described and explained. The questionnaire consists of three parts. First, the part related to personal characteristics is described. Then the part with questions related to the environmental behavior of the respondents is explained. Finally, the hypothetical situations are discussed.

5.1.1. Research method

Various methods are available for defining the user preferences. One of these methods is by using revealed data. Revealed data is derived from observations. In this method, persons are observed when for example choosing a particular room to work in. The data of the choices the respondents make by choosing a room to work in, are then observed and used in the study. It is difficult to carry out this choice experiment in classrooms, because pupils and teachers are dependent on the timetable of the school. This timetable determines for the teachers and pupils in which classroom they teach or receive lessons. It is therefore hard to observe where the persons prefer to work or join classes.

Another method to identify the user preferences is stated data. To acquire stated data, stated choice experiments can be conducted. With stated choice experiments, a set of choices is presented to the respondents. The respondents must make a choice between the different alternatives in hypothetical situations.

The advantage of stated data, compared with revealed data, is that in these experiments preferences can be given to new technologies (Hensher, Rose & Greene, 2015). This chapter examines the user preferences of new efficient technologies in school buildings. Therefore, in this research is chosen to use stated choice experiments. A disadvantage of stated data is that it cannot be determined with certainty what the user preferences are under real world conditions (Hensher, Rose & Greene, 2015).

To acquire stated data, questionnaires are used. According to Palvalin & Vuolle (2016), questionnaires are a feasible method for indicating the user preferences in a stated choice experiment. To analyze the data from the questionnaire, the random utility theory is used. This theory assumes that respondents make a choice between different alternatives based on their personal preferences. These personal preferences can be influenced by various factors. These may be personal characteristics or in the case of energy efficient and sustainable technologies, the characteristics of the energy efficient technologies.

In the acquired data, the respondents make choices between different alternatives based on multiple attributes. These attributes contain a certain utility. To determine the overall utility of a certain choice, the utility value of each attribute must be added up. By comparing the overall utility of different choices, the alternative that is preferred the most can be determined. To calculate the overall utility, the following formula is used (Hensher, Rose & Greene, 2015):

$$U_i = V_i + \varepsilon_i = \Sigma_n \beta_n X_{in} + \varepsilon_i \qquad (5.1)$$

U_i	=	Overall utility for alternative i
V_i	=	Structural utility for alternative i
ε_i	=	Random utility for alternative i
β_n	=	Parameter value of attribute n
X_{in}	=	Attribute values for all attributes n for alternative i

Now that the overall utility can be determined, also the probability can be calculated. The exponent of the overall utility of an alternative needs to be divided by the sum of the exponent of the overall utility of all alternatives. In this ways, the probability of an alternative chosen by an individual is determined. This is known as the multinomial logit (MNL) model using the following formula (Hensher, Rose & Greene, 2015):

$$P_{iq} = \frac{\exp(V_{iq})}{\Sigma_{i'} \exp(V_{i'q})} \qquad (5.2)$$

P_{iq}	=	Probability that individual q will choose alternative i
V_{iq}	=	Structural utility that individual q will choose alternative i

The multinomial logit (MNL) model is estimated with the statistical program NLOGIT5. In addition to the multinomial logit model, other discrete choice models can be used to determine the probability of an alternative chosen by an individual. A mixed logit (MXL) model can be used to capture heterogeneity among respondents. If the results of the observations vary widely and not mutually correspond among respondents, heterogeneity must be taken into consideration. A mixed logit model can then be used to give a better model estimation. The mixed logit model can be estimated by means of the following formula (Hensher, Rose & Greene, 2015; Wittink, 2011):

$$P_{iq} = \int \left(\frac{\exp(V_{iq})}{\Sigma_{i'} \exp(V_{i'q})} \right) f(\beta) d\beta \qquad (5.3)$$

P_{iq}	=	Probability that individual q will choose alternative i
V_{iq}	=	Structural utility that individual q will choose alternative i

In a mixed logit (MXL) model, a mix of the logit function is evaluated at different values of β with weights given by $f(\beta)$, herewith the mixed distribution of the model is handled (Wittink, 2011). The mixed logit model is estimated by means of the simulated likelihood estimation (Hensher, Rose & Greene, 2015).

The variables in the analysis are effect coded to analyze the variables as predictors in the model (Te Grotenhuis, Pelzer & Konig, 2017). Effect coding uses 1's, 0's and -1's. The principle of effect coding is displayed in table 11 in chapter 4. With effect coding, the coefficients of the level that is not estimated in the model is derived by multiplying the sum of the other levels by -1. In this way, the last level of the attribute serves as a base. Levels with a p-value lower than or equal as 0.05 are called statistically significant and can be considered as important in this model.

The questionnaire consists of three parts, namely personal characteristics, environmental behavior and user preferences.

5.1.2. Personal characteristics

The first part of the questionnaire consists of questions about the personal characteristics of the respondents. This part includes questions about among others their gender, year of birth, level of education and year of education. For gender, the respondents can choose between male or female. For the question about their year of birth, the respondents can choose from all numbers between 2010 and 1942, which are 69 choices. The respondents is also asked if they are a teacher or pupil. After this, pupils are asked what their level of education is. There can be chosen between vmbo-basis, vmbo-kader, vmbo-gl, vmbo-tl, havo, vwo or 'else, namely …'. Besides, the pupils is asked what their year of education is. A choice can be made from the 1st year to the 6th year. Teachers are asked what the level of education is of the pupils they educate. There can be chosen between primary education, vmbo-basis, vmbo-kader, vmbo-gl, vmbo-tl, havo, vwo or 'else, namely …'. In this question, multiple answers may be given. The variables of this part of the questionnaire are described in table 19. The table also indicates which questions are asked to pupils and which to teachers.

Table 19. Overview of the variables from the first part of the questionnaire including the personal characteristics

Variable	*Level of measurement*	*Type of question*	*Teacher or pupil questions*
Gender	Nominal	Multiple choice (2): 1 = Male 2 = Female	Both
Year of birth	Scale	Multiple choice (69) 1 = 2010 2 = 2009 3 = 2008 … 67 = 1944 68 = 1943 69 = 1942	Both
Level of education	Nominal	Multiple choice (7) 1 = vmbo-basis 2 = vmbo-kader 3 = vmbo-tl 4 = vmbo-gl 5 = havo 6 = vwo 7 = else, namely …	Pupils
Year of education	Nominal	Multiple choice (6) 1 = 1st year 2 = 2nd year 3 = 3rd year 4 = 4th year 5 = 5th year 6 = 6th year	Pupils
Level of education the teachers educate	Nominal	Multiple choice (7) (Multiple answers) 1 = primary education 1 = vmbo-basis 2 = vmbo-kader 3 = vmbo-tl 4 = vmbo-gl 5 = havo 6 = vwo 7 = else, namely …	Teachers

5.1.3. Environmental behavior

The literature study shows the behavior or attitude against the environment differs between adults and children (Eilam & Trop, 2012). Besides, is investigated that the energy consumption depends on the environmental behavior of persons (Sapsi & Consedine, 2014). To investigate if these findings also account for pupils and teachers, the environmental behavior of the respondents is investigated.

In the questionnaires, a part with questions about the environmental behavior of the respondents is included. These questions consists of statements. These statements are established in response to the literature study (Dunlap et al., 2002). The respondents must indicate to what extent these statements fit their personal opinion. The respondents can answer on these questions by means of a Likert scale, namely strongly disagree, disagree, undecided, agree or strongly agree (Brown, 2010). The statements in this part of the questionnaire are:

1 = Human are severely abusing the environment
2 = Comparing to a normal car, electric cars are suitable for my lifestyle
3 = Investing in energy saving facilities in dwelling are suitable for my life style
4 = I pay attention to my energy bill carefully
5 = To make sure I buy the right product, I often observe what others are buying and using
6 = Being environmentally responsible is an important part of who I am
7 = I often try new activities
8 = I have many different groups of friends
9 = I have very little free time

All the statements are submitted to teachers. A number of statements are excluded for pupils. Statement 2, 3 and 4 are not asked to the pupils, because the pupils are probably not in possession of their own house or car. That is why these statements are for the pupils left out of account.

5.1.4. Classroom preferences
The questionnaire also consists of questions which indicate the preference of the users for different classrooms. Hypothetical situations are presented to the respondents in this part of the questionnaire. The respondents must therefore assume that in a certain situation they have to make a choice between the two presented classrooms. These two classrooms have different characteristics regarding to the new energy efficient technologies examined in chapter 2 of this research.

In chapter 2 of this research, the different energy efficient technologies are described. These technologies are separated in different parts, namely heating/cooling, ventilation, renewable energy sources, energy storage and building automation. To limit the number of alternatives in this questionnaire, not all energy efficient technologies are included. In addition, some of these technologies do not have much impact on the user of the building or some are difficult to perceive for the respondents. To give a good indication of the preferences of the users, besides the energy efficient technologies, also the traditional technologies are included in this part of the questionnaire. This is done to investigate the interest in the energy efficient technologies in comparison with traditional systems.

For heating/cooling technologies, two technologies are combined and measured as one heating system, namely low temperature heating and thermally activated building systems. These two technologies together, provides an energy efficient system for heating a building. Radiant wall and ceiling panels are left out of consideration, because already a heat emitting system is used in this questionnaire. High temperature cooling has the same characteristics as low temperature heating, but it used as cooling system instead of heating system. That is why

HTC is left out of consideration in this questionnaire. Cogeneration and trigeneration are difficult to perceive, because for the respondents not much difference can be observed in comparison with traditional systems.

For ventilation, there is chosen to use balanced heat recovery system in the questionnaire. Earth-air tube ventilation is difficult for the respondents to perceive, because the respondents would not mention differences in comparison with conventional ventilation systems. Bauer Optimisation ventilation technology has not yet been scientifically researched, therefore this technology is not taken into account in this research.

As renewable energy source, various heat pumps are described in chapter 2 of this research. These heat pumps are difficult to perceive, because for the respondents not much difference can be noticed. The most important addition of these systems are energy efficiency and energy savings. Because the users of the school building do not have a grip on the energy bill of the school, the heat pumps are left out of consideration in this questionnaire. This also applies to solar water heaters. Solar panels are, according to the literature review, seen as the best known renewable energy source. These are therefore included in this literature review. Photovoltaic glazing is difficult to perceive, because for the respondents not much difference can be noticed.

For the energy storage technologies, the same applies to these technologies as some of the above, this mainly adds energy efficiency and energy savings to the school buildings. These technologies cannot be noticed in a classroom, that is why the technologies thermal energy storage, battery energy storage and smart grid are not taken into account in this questionnaire.

For building automation technologies, automatic lighting and automatic sun blinds are included in this questionnaire. According to the literature, these technologies are related to using the school building. It has emerged that the users of buildings experience disadvantages when these technologies are applied in buildings. These technologies are applied in the questionnaire to see if the users of the school buildings think the same about these technologies then about traditional systems for lighting and sunshades. Automatic daylight control is not taken into consideration in this questionnaire. With this technologies implemented in the building, the building user should not observe any disadvantages, because lighting with automatic daylight control is adjusted to the amount of sunlight that a room appears. For respondents, this adjustment of the lighting using daylight control must not be noticeable and therefore it is difficult to perceive in this questionnaire.

Of the 23 energy efficient technologies that are applicable in school buildings, 6 are used in the questionnaire. Two technologies are combined into one variable, resulting in 5 variables. These variables are: heating system, ventilation system, photovoltaic panels, lighting and sun blinds. For these 5 variables, the choice was made to keep the questionnaire in balance and not to become too complex, so that making a choice for the respondents will be not too difficult. Table 20 shows which technologies are used in the questionnaire and the reason for this.

Table 20. Overview of the energy efficient technologies

Technology	*Used?*	*Comment/requirement*	*Attribute*
Radiant ceiling/wall panels	No	Another heat emitting system is used	
Thermally activated building systems	Yes	Combined with LTH	Heating system
Low temperature heating (LTH)	Yes	Combined with TABS	Heating system
High temperature cooling (LTH)	No	Similar characteristics as LTH	
Cogeneration	No	Difficult for respondents to notice	
Trigeneration	No	Difficult for respondents to notice	
Balanced heat recovery systems	Yes		Ventilation system
Earth-air tube ventilation	No	Difficult for respondents to notice	
Horizontal ground source heat pump	No	Difficult for respondents to notice	
Vertical ground source heat pump	No	Difficult for respondents to notice	
Groundwater heat pump	No	Difficult for respondents to notice	
Air to air heat pump	No	Difficult for respondents to notice	
Air to water heat pump	No	Difficult for respondents to notice	
Heat pump water heater	No	Difficult for respondents to notice	
Photovoltaic panels	Yes		Photovoltaic (PV) panels
Photovoltaic glazing	No	Difficult for respondents to notice	
Solar water heater	No	Difficult for respondents to notice	
Thermal energy storage	No	Difficult for respondents to notice	
Battery energy storage	No	Difficult for respondents to notice	
Smart grid	No	Difficult for respondents to notice	
Automatic lighting	Yes		Lighting
Automatic sun blinds	Yes		Sun blinds
Automatic daylight control	No	Difficult for respondents to notice	

In the questionnaire the technologies are described on the basis of their characteristics with regard to comfort in a classroom. According to Buso et al. (2017), comfort can be explained in several items, air quality, temperature, noise and light. By assuming these items, comfort can be made measurable for the respondents when completing the questionnaire (Buso et al., 2017). For the respondents the energy efficient technologies are converted into their advantages and disadvantages. For this purpose the items for comfort can be used to make the energy efficient technologies measurable. Of each of the 5 mentioned variables, both the energy efficient technology and the traditional system are used. This determines the extent to which the respondents assess energy-efficient technologies compared to traditional systems.

Class size

In addition to the earlier mentioned variables, also a constant variable is added to the questionnaire. This is the variable class size. Class size is a constant variable because in every choice set the variable has a constant value. According to Barrett et al. (2016), class size is influencing the level of comfort in a classroom. If a large class is educated in a classroom, the classroom warms up faster than with a small class size (Barrett, Barrett & Zhang, 2016). A small class size is a class with 19 pupils, large classes contains 33 pupils (Blatchford, Edmonds & Martin, 2003). In every choice set this constant variable is equal, so this variable is implemented in the question. So the respondent have to consider choices for a large class size and for small class size. This constant variable can be interpreted in the model as a correction of the constant. This will be explained in subsection 5.3.2.

Heating system
As heating system, low temperature heating and thermally activated building systems are combined. This is an energy efficient combination for heating a building. According to the literature review, this combination reduces greenhouse gas emissions in comparison with traditional heating systems. Also in comparison with traditional heating systems, with this combination it takes more time to warm up the building. With traditional heating system the building is warmed up more quickly.

Ventilation system
A balanced heat recovery system is an energy efficient heating system for applying ventilation to the building. It provides more fresh air than by using natural ventilation. According to the literature, a drawback of this system is that it produces background noise. Traditional ventilation is a more silent solution.

Lighting
Automatic lighting is very energy efficient. The lights are only switched on when movements in the room are detected. But this can also be a disadvantage, if a person it working outside the range of the motion sensors, the lights will be switched of.
Photovoltaic (PV) panels
PV panels generates electricity by means of a natural energy source, namely solar energy. This system is energy efficient and reduces greenhouse gas emissions. According to the literature review, PV panels can sometime generate less energy. If the schools are off-grid, this will result in less energy for warming the building, so a lower room temperature, in comparison with conventional energy sources.

Sun blinds
Automatic sun blinds are automatically managed by means of the brightness of the sunshine. This system does not take into account of the activity that takes place in the classroom. If the sun shines bright the sun blinds will be lowered. This can cause noise in the middle of the lesson.

In table 21, the above mentioned attributes and their levels are described. The levels of the five systems in the buildings are based on the traditional system (level 0) and the energy efficient technology (level 1).

Table 21. Attributes and levels of the questionnaire

Attribute number	*Appointed attribute*	*Level 0*	*Level 1*
1	Class size	Large (33 pupils)	Small (19 pupils)
2	Heating system	20% more greenhouse gas emissions and the classroom is quickly warmed up *	20% less greenhouse gas emissions and at the end of the lesson the classroom is warmed up **
3	Ventilation system	Quiet classroom with polluted air	Fresh air and background noise by ventilation system
4	Lighting	After the lesson the lights need to be switched off manually	Lighting switches off if no movements are detected
5	PV panels	10% more greenhouse gas emissions and healthy room temperature (21 °C) *	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C) **
6	Sun blinds	Sun blinds need to be done manually	Noise in the middle of the lessons due to lower the sun blinds automatically

**: More than conventional systems*
***: Less than energy efficient systems*

After indicating the attributes and their levels, the levels of each attribute are recoded by means of effect coding. A sample of the effect coding principle is displayed in table 11. With the recoded attributes the analysis can be conducted. The result of effect coding is displayed in table 22 below.

Table 22. Results effect coding

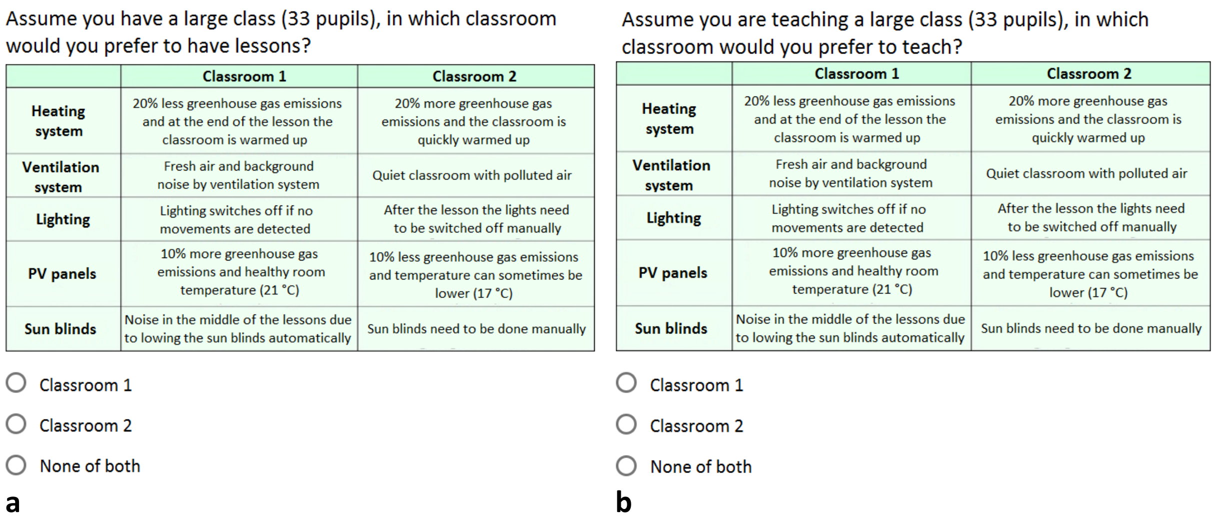
Attribute number	*Appointed attribute*	*Level 0*	*Level 1*
1	Class size (Constant variable)	1	-1
2	Heating system	1	-1
3	Ventilation system	1	-1
4	Lighting	1	-1
5	Photovoltaic (PV) panels	1	-1
6	Sun blinds	1	-1

The situations in the questionnaires contains of 2 alternatives. In each situation the constant variable class size is included in the question. Each profile consist of two alternatives with 5 attributes (heating system, ventilation system, lighting, PV panels and sun blinds) and a constant variable (class size). This results in profiles with 11 attributes. The full factorial design of 11 attributes with 2 levels results in 2048 profiles ($2^{11} = 2048$). To limit the amount of choice sets a fractional factorial design of 24 profiles is established by using the orthogonal design function in SPSS (IBM, 2016). The fractional factorial design is displayed in table 23. The fractional factorial design in words can be retrieved in appendix H. The questionnaire of this research is separated in two parts of 12 profiles. The two separated questionnaires are submitted to other respondents. Each respondent fills in only one of the two questionnaires. The personal questions and the questions about environmental behavior are the same in both questionnaire.

Table 23. Fractional factorial design of 24 profiles

Profile	Class size	Heating system	Ventilation system	Lighting	PV panels	Sun blinds	Heating system	Ventilation system	Lighting	PV panels	Sun blinds
1	1	-1	1	-1	-1	1	1	-1	1	1	-1
2	1	-1	1	1	1	-1	-1	1	1	-1	-1
3	1	1	-1	1	-1	-1	1	-1	1	-1	1
4	1	1	-1	-1	1	-1	1	1	-1	1	-1
5	1	-1	-1	-1	1	1	1	1	1	-1	1
6	1	1	1	-1	1	1	-1	-1	-1	-1	1
7	-1	-1	1	-1	-1	1	1	-1	1	1	-1
8	-1	-1	1	1	1	-1	-1	1	1	-1	-1
9	-1	1	-1	1	-1	-1	1	-1	1	-1	1
10	-1	1	-1	-1	1	-1	1	1	-1	1	-1
11	-1	-1	-1	-1	1	1	1	1	1	-1	1
12	-1	1	1	-1	1	1	-1	-1	-1	-1	1
13	1	1	1	-1	-1	-1	-1	1	1	1	1
14	1	-1	1	1	1	-1	1	-1	-1	1	1
15	1	1	-1	1	1	1	-1	-1	1	1	-1
16	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
17	1	1	1	1	-1	1	1	1	-1	-1	-1
18	1	-1	-1	1	-1	1	-1	1	-1	1	1
19	-1	1	1	-1	-1	-1	-1	1	1	1	1
20	-1	-1	1	1	1	-1	1	-1	-1	1	1
21	-1	1	-1	1	1	1	-1	-1	1	1	-1
22	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
23	-1	1	1	1	-1	1	1	1	-1	-1	-1
24	-1	-1	-1	1	-1	1	-1	1	-1	1	1

In both the questionnaires 12 profiles are presented. In this way all the attributes of the fractional factorial design are implemented in the questionnaires. In addition to these choice sets, the respondents have the ability to answer the questions with 'none of both'. Figure 19, show a sample of the choice sets presented in the questionnaires. In figure 19a the choice sets for pupils is presented, figure 19b shows the choice set for teachers.



Assume you have a large class (33 pupils), in which classroom would you prefer to have lessons?

	Classroom 1	Classroom 2
Heating system	20% less greenhouse gas emissions and at the end of the lesson the classroom is warmed up	20% more greenhouse gas emissions and the classroom is quickly warmed up
Ventilation system	Fresh air and background noise by ventilation system	Quiet classroom with polluted air
Lighting	Lighting switches off if no movements are detected	After the lesson the lights need to be switched off manually
PV panels	10% more greenhouse gas emissions and healthy room temperature (21 °C)	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)
Sun blinds	Noise in the middle of the lessons due to lowing the sun blinds automatically	Sun blinds need to be done manually

Classroom 1

Classroom 2

None of both

a

Assume you are teaching a large class (33 pupils), in which classroom would you prefer to teach?

	Classroom 1	Classroom 2
Heating system	20% less greenhouse gas emissions and at the end of the lesson the classroom is warmed up	20% more greenhouse gas emissions and the classroom is quickly warmed up
Ventilation system	Fresh air and background noise by ventilation system	Quiet classroom with polluted air
Lighting	Lighting switches off if no movements are detected	After the lesson the lights need to be switched off manually
PV panels	10% more greenhouse gas emissions and healthy room temperature (21 °C)	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)
Sun blinds	Noise in the middle of the lessons due to lowing the sun blinds automatically	Sun blinds need to be done manually

Classroom 1

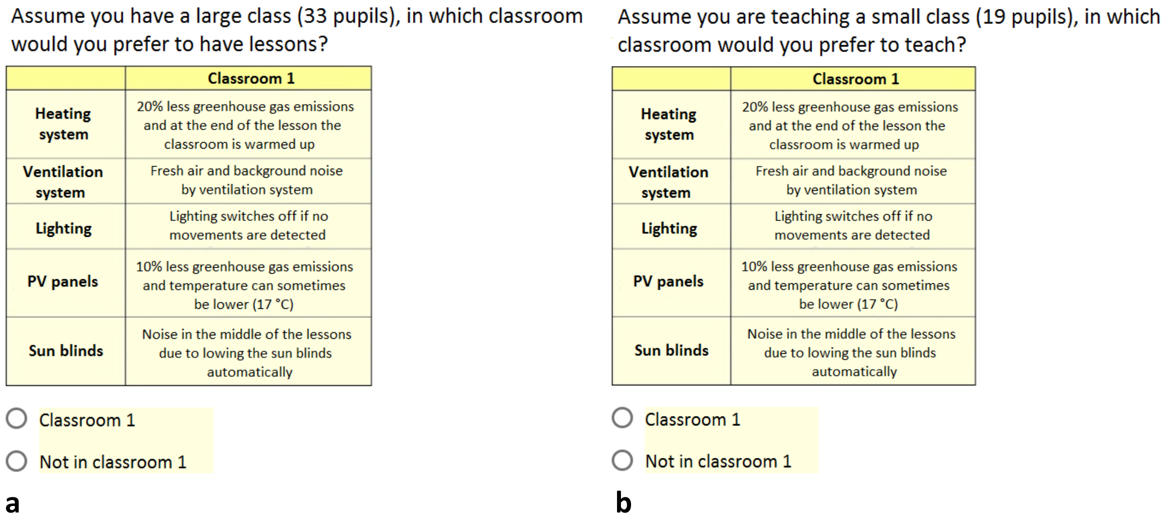
Classroom 2

None of both

b

Figure 19. (a) Pupil's choice set. (b) Teacher's choice set.

In the fractional factorial design, profiles 16 and 22 have the same variables for the first 5 technologies as for the last 5 technologies. To maintain the balance of the questionnaire, profile 16 and 22 are used in the questionnaires. But in the questions with these profiles, only one alternative is presented. The respondents can answer this question with two options, namely 'classroom 1' and 'not in classroom 1', this is also displayed in figure 20. In figure 20a the choice sets for pupils is presented, figure 20b shows the choice set for teachers.



Assume you have a large class (33 pupils), in which classroom would you prefer to have lessons?

	Classroom 1
Heating system	20% less greenhouse gas emissions and at the end of the lesson the classroom is warmed up
Ventilation system	Fresh air and background noise by ventilation system
Lighting	Lighting switches off if no movements are detected
PV panels	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)
Sun blinds	Noise in the middle of the lessons due to lowing the sun blinds automatically

○ Classroom 1

○ Not in classroom 1

a

Assume you are teaching a small class (19 pupils), in which classroom would you prefer to teach?

	Classroom 1
Heating system	20% less greenhouse gas emissions and at the end of the lesson the classroom is warmed up
Ventilation system	Fresh air and background noise by ventilation system
Lighting	Lighting switches off if no movements are detected
PV panels	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)
Sun blinds	Noise in the middle of the lessons due to lowing the sun blinds automatically

○ Classroom 1

○ Not in classroom 1

b

Figure 20. (a) Pupil's choice set. (b) Teacher's choice set.

5.2. Data description

In this section, the acquired data is described. First, the distribution of the questionnaire is discussed. After that the three parts of the questionnaire are covered, namely personal characteristics, environmental behavior and user preferences.

5.2.1. Distribution of the questionnaire

In this questionnaire teachers of primary and secondary schools and pupils of secondary schools are asked to respond. In total 397 respondents have completed one of the two questionnaires. The first questionnaire is completed by 215 persons and the second by 182 persons. Of these respondents 21 questionnaires are filled in incorrectly. The persons filling in these questionnaires, entered no variation in answers in the user preferences part of the questionnaire or entered impossible answers. For example, someone filled in to be a pupil born in 1942, sitting in the 6th grade of vmbo. Vmbo schools only educate up to the 4th grade and born 1942 (age: 76) seems a bit too old to be in the secondary school.

In questionnaire 1, 14 respondents filled in incorrectly and 7 respondents in questionnaire 2 (green parts of the bar charts). The distribution of the questionnaire is also displayed in figure 21. After excluding the useless questionnaires, there remains 376 useful questionnaires.

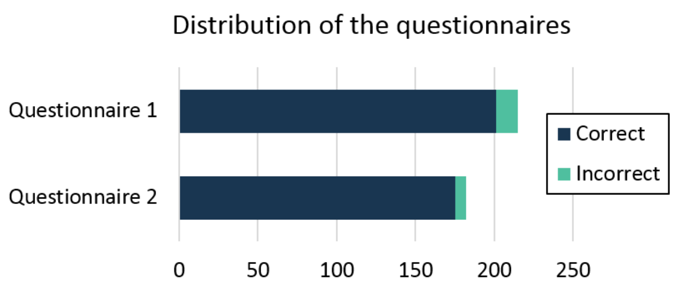


Figure 21. Schematic diagram of the distribution of the questionnaire

5.2.2. Personal characteristics

To give insight in the type of respondents in this questionnaire, the personal characteristics are described. The questionnaire is completed by 83 teachers (22%) and 293 pupils (78%). The ratio is also displayed in figure 22.

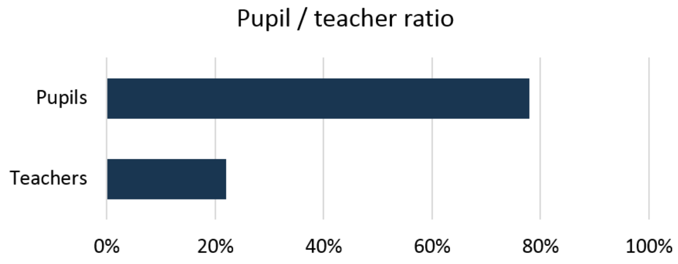


Figure 22. Pupil/teacher ratio

For gender, the respondents were able to fill in two answers, namely male or female. Of these total 376 respondents, 154 men (41%) and 222 women completed the questionnaire. This can also be seen in figure 23.

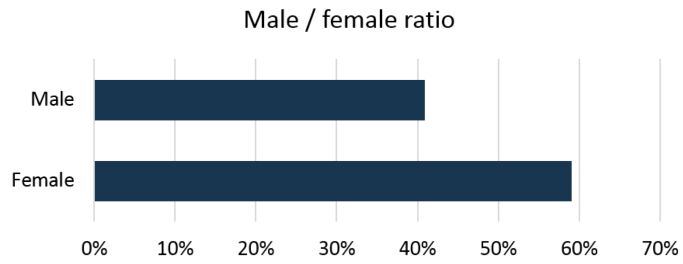


Figure 23. Male/female ratio

The respondents are asked to fill in their year of birth. With this data, the age of the respondents can be determined. With the ages, different age groups can be classified. According to Pew Research Center (2015), different age groups are: children (ages 0-17), millennial (ages 18-34), gen x (ages 35-50), boomer (ages 51-69) and silent (ages 70-87). The respondents are classified by means of these age groups, see figure 24. As can be seen in this figure, many respondents are between 0 and 17 years old (228 respondents). The age group 'Millennial' is represented by 95 respondents (25%). 'Gen X' and 'Boomer' consist of respectively 29 (8%) and 24 respondents (6%). As expected, none of the respondents are between 70 and 87 years old.

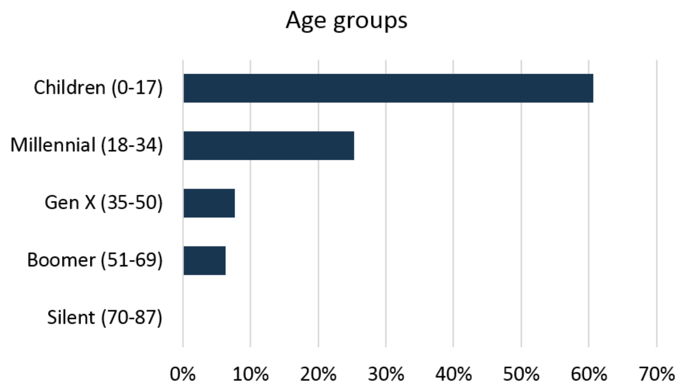


Figure 24. Age groups

For the level of education, the pupils were able to fill in seven answers, namely vmbo-basis, vmbo-kader, vmbo-tl, vmbo-gl, havo, vwo and 'else, namely …'. These are all the levels of education of the Dutch secondary schools. Some of the schools combine havo and vwo.

Therefore, some of the respondents filled in the choice 'else, namely ...'. The levels of vmbo are translated as 'Lower Secondary Education'. The levels havo and havo/vwo are translated to 'Higher Secondary Education'. And the respondents who answered this question with vwo, are placed in the group 'Pre-University Education'. Figure 25 displays the distribution of the level of educations in this questionnaire. Only 6 respondents (2%) are 'Lower Secondary Education' students. 77 pupils (20%) are educated at the level 'Higher Secondary Education'. The group 'Pre-University Education' is represented by 210 respondents (56%).

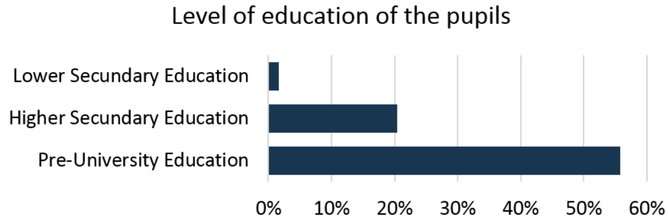


Figure 25. Level of education of the pupils

The year of education is also only completed by the pupils. This indicates in which grade the pupil is in. The pupils were able to fill in six answers, namely from 1st year to 6th year. 26 of the respondents (7%) are in the first grade. 57 pupils (15%) are in the second year of their education. The 3rd year is represented by 52 respondents (14%) and the 4th year by 56 respondents (15%). The 5th grade and the 6th grade consists of respectively 65 (17%) and 37 respondents (10%). In figure 26, the distribution of the year of education of the respondents is displayed.

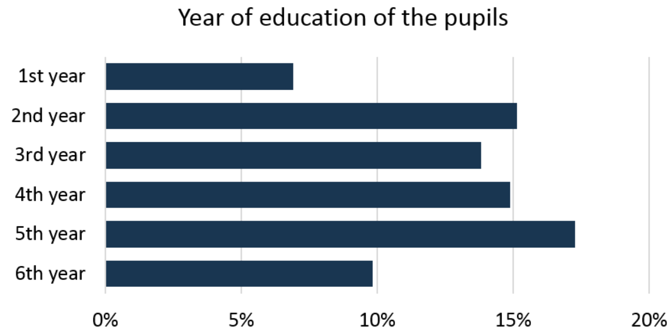


Figure 26. Year of education of the pupils

The level of education the teachers educate to is from now on called teach level in this research. The teach level is only filled in by the teachers in this questionnaire. The teachers were able to fill in seven choices, but multiple answers were allowed to fill in. Therefore different combinations came out of the questionnaire. 18 respondents (5%) are educating to 'Primary Education'. 'Lower Secondary Education' is educated by 12 respondents (3%) and 'Pre-University Education' by 11 respondents (3%). None of the respondents is teaching only 'Higher Secondary Education'. 'Lower & Higher Secondary Education' is represented by 3 respondents (1%). The group 'Higher Secondary & Pre-University Education' and the group 'All Secondary Educations' consists of respectively 34 (9%) and 5 respondents (1%). In figure 27, the distribution of the teach level of the teachers is displayed.

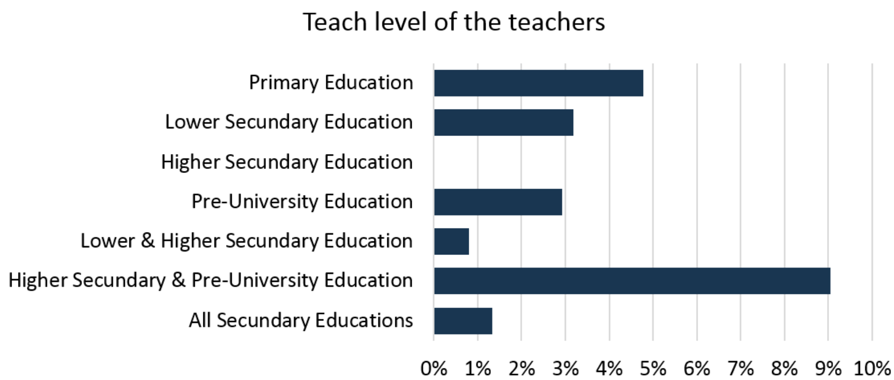


Figure 27. Teach level of the teachers

5.2.3. Environmental behavior

This part of the questionnaire consists of statements to give insight in the environmental behavior of the respondents. The statements used in this questionnaire are:

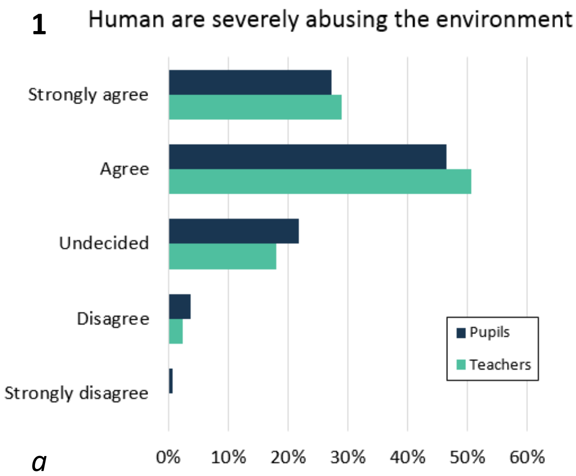
1 = Human are severely abusing the environment
2 = Comparing to a normal car, electric cars are suitable for my lifestyle
3 = Investing in energy saving facilities in dwelling are suitable for my lifestyle
4 = I pay attention to my energy bill carefully
5 = To make sure I buy the right product, I often observe what others are buying and using
6 = Being environmentally responsible is an important part of who I am
7 = I often try new activities
8 = I have many different groups of friends
9 = I have very little free time

In figure 28, the distribution of this part of the questionnaire can be obtained. The distribution of the teachers is displayed as a green bar chart and the distribution of the pupils as a dark blue bar chart. Statements 2, 3 and 4 are only answered by the teachers, as mentioned in subsection 5.1.3.

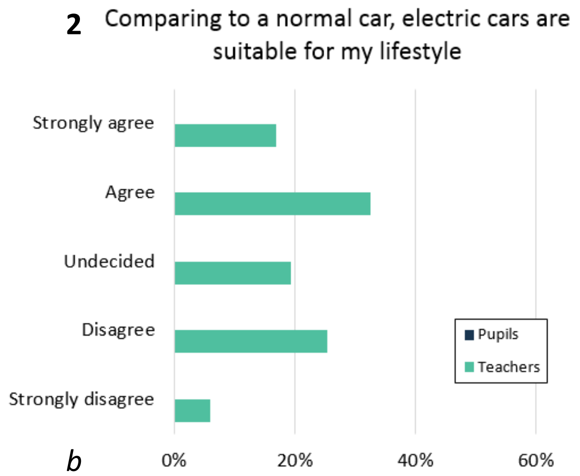
For statement 1, teachers are more likely to agree with the statement in comparison with pupils. This also accounts for statement 6. In the literature study is investigated that older individuals are more likely to be environmental friendly. The results on statements 1 and 6 prove that teachers are more likely to be environmental friendly and more energy conscious in comparison with pupils.

Statement 3 shows that teachers are inclined to purchase energy saving facilities for their home. It can also be seen that an electric car fits their lifestyle and that they are inclined to keep an eye on their energy bill. From these answers you could therefore state that teachers in this survey are aware of their energy consumption and use it economically.

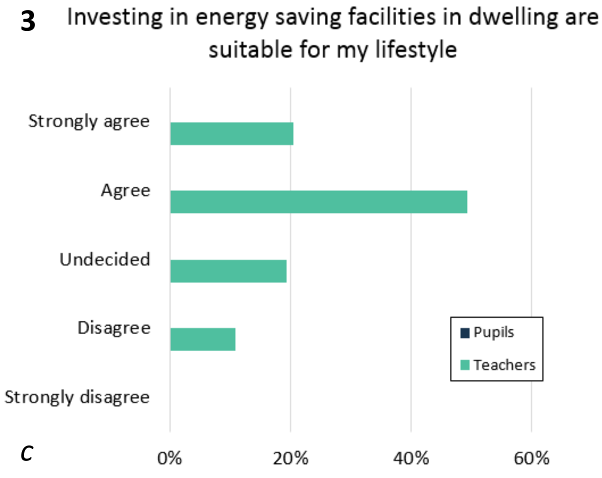
Statement 5 shows that teachers are less likely to determine their purchases based on what other people use, compared to pupils. In addition, teachers are also more likely to undertake new activities with regard to pupils. Teachers in this survey more often find that they have little free time with regard to pupils. Finally, for statement 8, teachers are more likely to agree with the statement in comparison with pupils. But teachers are also more likely to disagree with statement 8 in comparison with pupils.

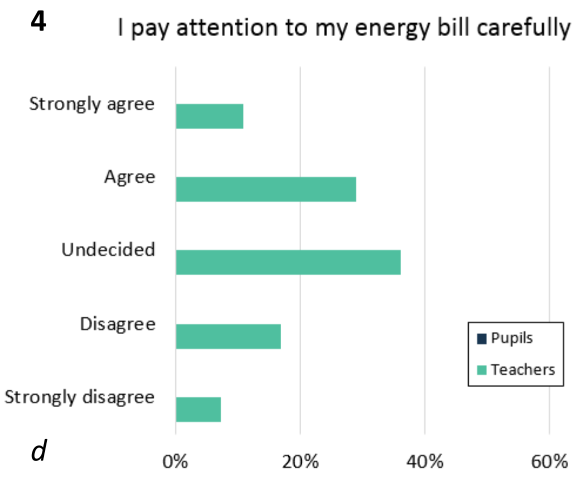


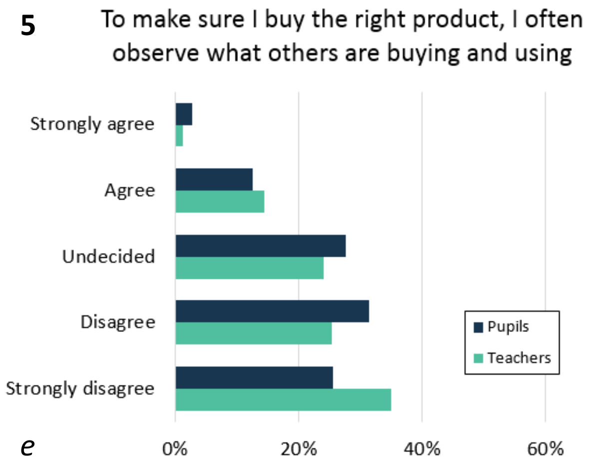
a

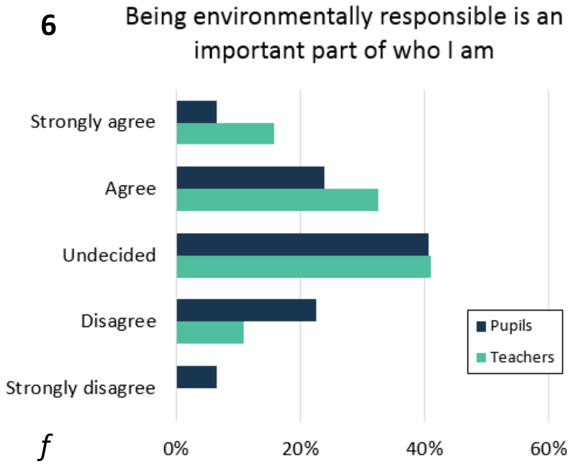


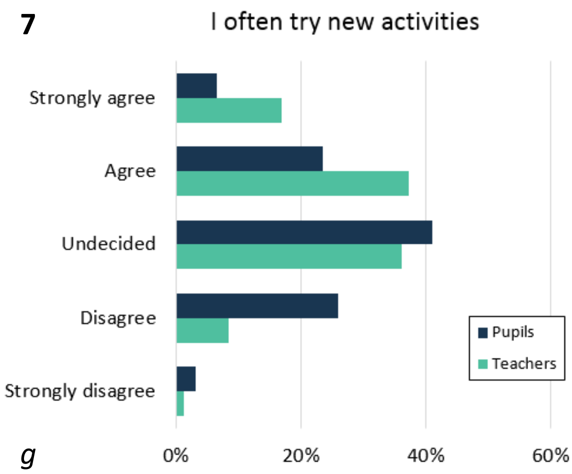
b


3
Investing in energy saving facilities in dwelling are suitable for my lifestyle
Strongly agree
Agree
Undecided
Disagree
Strongly disagree
Pupils
Teachers
c
0%
20%
40%
60%


4
I pay attention to my energy bill carefully
Strongly agree
Agree
Undecided
Disagree
Strongly disagree
Pupils
Teachers
d
0%
20%
40%
60%


5
To make sure I buy the right product, I often observe what others are buying and using
Strongly agree
Agree
Undecided
Disagree
Strongly disagree
Pupils
Teachers
e
0%
20%
40%
60%


6
Being environmentally responsible is an important part of who I am
Strongly agree
Agree
Undecided
Disagree
Strongly disagree
Pupils
Teachers
f
0%
20%
40%
60%


7
I often try new activities
Strongly agree
Agree
Undecided
Disagree
Strongly disagree
Pupils
Teachers
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0%
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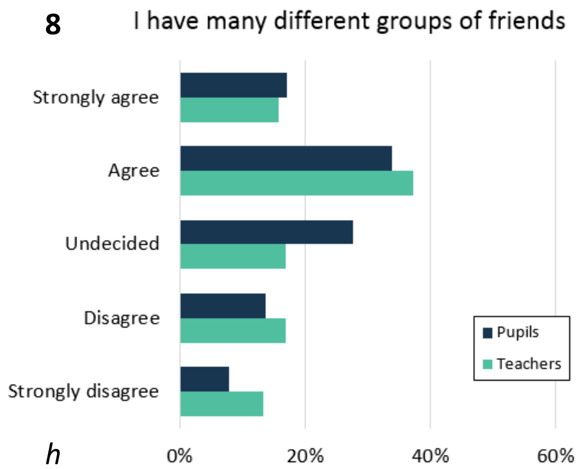
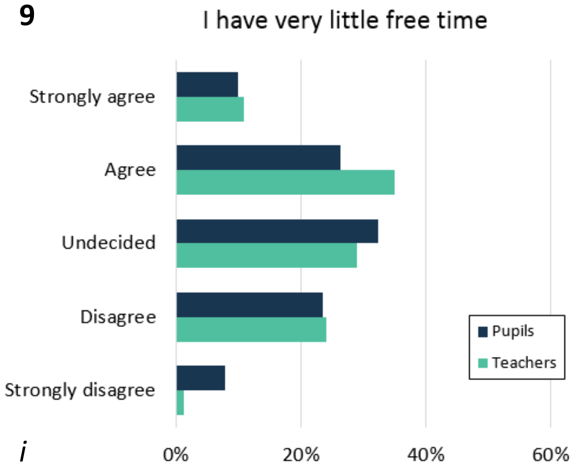

8
I have many different groups of friends
Strongly agree
Agree
Undecided
Disagree
Strongly disagree
Pupils
Teachers
h
0%
20%
40%
60%

9



i

Figure 28. (a) Distribution of statement 1. (b) Distribution of statement 2. (c) Distribution of statement 3. (d) Distribution of statement 4. (e) Distribution of statement 5. (f) Distribution of statement 6. (g) Distribution of statement 7. (h) Distribution of statement 8. (i) Distribution of statement 9.

5.2.4. Class room preferences

The third part of the questionnaire consists of questions to indicate the school building user preferences of classrooms with different characteristics. In subsection 5.1.4., 24 profiles with 48 alternatives are explained. The questionnaire is separated in two parts. The respondents only completed one of the questionnaires. In each part 12 choice sets with 24 alternatives are presented. Each question consists of 2 choices (classroom 1 or classroom 2) and a 'none of both'-choice. The pupils are answering the following questions:

- *Assume you have a large class (33 pupils), in which classroom would you prefer to have lessons?*
- *Assume you have a small class (19 pupils), in which classroom would you prefer to have lessons?*

The questionnaire of the pupils with 12 choice sets is filled in 293 times. This results in 3516 observations (293 respondents * 12 choice sets).

The teachers are answering the following questions:

- *Assume you are teaching a large class (33 pupils), in which classroom would you prefer to teach?*
- *Assume you are teaching a small class (19 pupils), in which classroom would you prefer to teach?*

The questionnaire of the teachers with 12 choice sets is filled in 83 times. This results in 996 observations (83 respondents * 12 choice sets).

In total, both questionnaires are filled in correctly 376 times. If the teacher dataset and the pupil dataset are combined, this results in 4512 observations (376 respondents * 12 choice sets).

5.3. Results

In this section, the results of the multinomial logit (MNL) model and the mixed logit (MXL) models are presented. First the performances of the models are determined. Thereafter, the coefficients of the attributes are displayed and explained. Finally the conclusion and limitations are described.

5.3.1. Model performance

As explained in subsection 4.4.1., the model performance is determined based on the rho square (ρ^2), see appendix I. In table 24, the ρ^2's are displayed for three datasets, the pupil dataset including only the pupil observations, the teacher dataset including only the teacher observations and the combined dataset including the pupil and teacher observations. As can be seen in table 24, the ρ^2 of the estimated models is varying between 0.09 and 0.17. These values for ρ^2 are relatively low. This means the data does not fit the estimated models very well. What also can be seen, is the ρ^2 increases when choosing a mixed logit (MXL) model instead of a multinomial logit (MNL) model for all the three datasets. As explained in subsection 5.1.1., MXL models capture heterogeneity among the respondents. The model fits the data better when using a MXL model. This means the preferences of the respondents are heterogeneous. In this case, a MXL model can give a better model estimation according to the choices of the respondents.

Table 24. Rho squares (ρ^2's)

	Pupil dataset	*Teacher dataset*	*Combined dataset*
rho² MNL model	0.1446	0.0925	0.1243
rho² MXL model	0.1746	0.1433	0.1577

5.3.2. Model estimation

In this analysis, three mixed logit models are estimated. These three models are based on three datasets, the pupil dataset including only the pupil observations, the teacher dataset including only the teacher observations and the combined dataset including the pupil and teacher observations. In appendix J the output of the pupil model can be obtained, in appendix K the output of the teacher model can be obtained and in appendix L the output of the combined model can be obtained.

The constant term in these models is defined as the indicator for choosing one of the alternatives above the "none of both" option. If the constant is positive, this means the respondents choose one of the alternatives above the none of both option. If the constant is negative, the respondents are likely to choose the none of both option above the two alternative options.

In this analysis, the class size is a constant variable and can be interpreted in the model as a correction of the constant. A large class size is effect coded as 1 and a small class size as -1. As correction of the constant, the constant of a large class size in the pupil dataset is 0.87895 (constant coefficient + (1 * class size coefficient)). The constant for a small class size in the pupil dataset is 0.90721. For the teacher dataset the constant of a large class size is -0.12246 and the constant for a small class size is 0.14728. For the combined dataset the constant of a large class size is 0.63578 and the constant for a small class size is 0.72848. As can be concluded is that the teachers are more likely to choose the none of both option when the class size is large. When the class size is small, the teachers are likely to choose one of the alternatives. For the pupil dataset and the combined dataset, the respondents are in both class sizes more likely to choose one of the alternatives above the none of both option.

Table 25. Coefficients of the three MXL models

	Pupil dataset		*Teacher dataset*		*Combined dataset*	
	Coefficients		*Coefficients*		*Coefficients*	
Constant	.89308	***	.01241		.68213	***
Class size	-.01413		-.13487	*	-.04635	
Heating system	-.02455		-.05175		-.02670	
Ventilation system	-.64233	***	-.74691	***	-.66179	***
Lighting system	.22385	***	.37289	***	.25395	***
PV panels	.21896	***	-.01879		.18112	***
Sun blinds	.33668	***	.28438	***	.31249	***

**: 90% significance*
****: 99% significance*

In the mixed logit model including the pupil dataset, all the attributes except heating system and class size are statistically significant. This also accounts for the combined model. For the teacher model, the attributes ventilation system, lighting system and sun blinds are statistically significant. The class size is in this model for 90% significant.

In the questionnaires, the attributes are specified as the advantages and disadvantages of the technologies. In subsection 5.1.4., the specifications of each attribute is described. This ways of attribute specification must be taken into account when interpreting the model results. For example for PV panels, the respondents are likely to choose the traditional choice based on the lower room temperature and not based on the technology.

As can be seen in table 25, type of ventilation system is in all the three models the most influencing factor on the choice of a class room. As can be seen in table 22 in subsection 5.1.4., the conventional technologies are effect coded as 1 and the energy efficient technologies are effect coded as -1. In table 25, the positive coefficients prove the respondents are more likely to choose the conventional technology above the energy efficient technologies and the negative coefficients prove the respondent are more likely to choose the energy efficient technology. For the heating and ventilation systems, the respondents are more likely to choose the energy efficient technology above the conventional system. The teachers are more likely to choose PV panels above no PV panels, although not significantly. In the pupil dataset and combined dataset the respondents are more likely to choose for not having PV panels. For the lighting system and sun blinds the respondents prefer the conventional systems above the energy efficient technologies. Note that these results are based on the advantages and disadvantages of these systems.

As described in the previous section, the preferences of the respondents are heterogeneous. This can be determined from the standard deviations. For each attribute, the standard deviation shows the amount of variation of the preferences of the respondents around the mean preference for that attribute. If the standard deviation is low, the preferences of the respondents are close to the mean. If the standard deviation is high, the preferences of the respondents are spread out over a wider range and vary more between the respondents. The means of the attributes are the parameters shown in table 25. The standard deviations of these attributes show the dispersion of the data points. In table 26, the standard deviation of the three datasets is shown. As can be seen is that the standard deviations are relatively high, except for the class size. High standard deviations prove that the preferences of the respondents vary a lot. This means the preferences of the respondents are heterogeneous.

Table 26. Standard deviations of the three MXD logit models

	Standard deviations					
	Pupil dataset		*Teacher dataset*		*Combined dataset*	
Size	.00739		.00584		.00789	
Heating system	.33592	***	.52548	***	.37798	***
Ventilation system	.59628	***	.73364	***	.62164	***
Lighting	.33527	***	.55570	***	.36749	***
PV panels	.48522	***	.47618	***	.48595	***
Sun blinds	.37512	***	.57482	***	.40576	***

****: 99% significance*

In subsection 5.2.3. is proven the teachers in this questionnaire are more likely to be energy conscious in comparison with pupils. Comparing the model including the pupil dataset and the model including the teacher dataset prove that teachers are more likely to choose the energy efficient technology for heating system and ventilation system comparing to pupils. Teachers are also likely to choose PV panels above no PV panels, as pupils prefer to have no PV panels. But teachers are also more likely to choose the traditional lighting system compared to pupils. And at least teachers are less likely to choose the traditional sun blinds in comparison with pupils. This concludes, that teachers are generally more likely to be energy conscious comparing to pupils. Also here must be noted that these results are based on the advantages and disadvantages of these systems.

5.4. Conclusion and discussion

5.4.1. Conclusion

To indicate the school building user preferences on energy efficient technologies, a discrete choice experiment is conducted. The respondents in this questionnaire are teachers on primary and secondary schools and pupils on secondary schools. The questionnaire consists of three parts, a personal characteristic part, an environmental behavior part and the part with hypothetical choice situations. In the environmental part is proved that the teachers in this questionnaire are more likely to be environmental friendly and energy conscious in comparison with pupils.

For the discrete choice experiment including the hypothetical situations, three mixed logit models are estimated. The preferences are widely spread between respondents and for this reason heterogeneous. Mixed logit models capture the heterogeneity among respondents. Model 1 includes the pupil dataset, model 2 includes the teacher dataset and model 3 includes both the datasets. The results of this questionnaire proved (based on the advantages and disadvantages of the technology) that the ventilation system is for both pupils and teachers the most influencing factor on the choice of a class room. In all the 3 models, the energy efficient ventilation system is chosen above the conventional system. This also account for the heating system. For lighting system and sun blinds, both the pupil and teachers are likely to choose the conventional system above the energy efficient system. For PV panels, the teachers are slightly likely to choose to have PV panels while pupils prefer not having solar panels. There must be noted that these results are based on the advantages and disadvantages of these technologies.

Based on the results in this questionnaire, the teachers are more likely to choose the energy efficient technologies in comparison with pupils. There can be concluded that teachers are more energy conscious in comparison with pupils.

5.4.2. Discussion

In this questionnaire only 6 of the 23 investigated energy efficient technologies are included. To indicate the user preference on all 23 energy efficient technologies, further research must be conducted.

6. CONCLUSION

In this chapter, the conclusions are specified based on the outcomes of the research. After that the recommendations and future research are described. In section 6.3. the managerial implications are discussed.

6.1. Conclusion

The goal of this research was to indicate which energy efficient technology can be technically applied in school buildings. Besides, the preferences of school building users on these technologies had to be identified. This resulted in the following research question:

> *"Which energy efficient technologies are technically applicable in school buildings according to the requirements for nearly zero-energy buildings and what are the school building user preferences for these technologies?"*

To answer the main research question, the following sub questions are determined:

I. Which energy efficient technologies can be implemented to decrease the school buildings energy consumption according to the requirements for nearly zero energy buildings?
II. Which technologies can be implemented to improve the school buildings energy efficiency according to the requirements for nearly zero energy buildings?
III. Which technologies can be implemented to increase the amount of renewable energy in school buildings and how can the surplus electricity be stored?
IV. What is the energy consumption pattern of school buildings?
V. Which technologies are useful according to the energy consumption pattern of school buildings?
VI. Which factors influence the school building's energy consumption?
VII. What are the school building user preferences on the energy efficient technologies?

To determine which energy efficient technologies can be applied in school buildings to decrease the amount of energy consumption, increase the energy efficiency and increase the share of renewable energy sources, a literature study is conducted. In this literature study is concluded that multiple energy efficient technologies can be technically applied in school buildings.

The technologies which can be technically applied to increase the share of renewable energy sources are horizontal and vertical ground source heat pumps, groundwater heat pumps, air to air and air to water heat pumps, heat pump water heaters, solar water heaters, PV panels and PV glazing. These nine technologies are also energy efficient because of the use of a natural heat source. To capture the generated energy, three energy storage systems can be used, namely thermal energy storage, battery energy storage and smart grid.

The energy efficient technologies which proved to reduce the energy consumption are cogeneration and trigeneration, balanced heat recovery systems, earth-air tube ventilation and three building automation technologies, namely automatic lighting, automatic sun blinds and automatic daylight control. These seven technologies are also proved to be energy efficient.

To upgrade the level of energy efficiency in school building also four other technologies can be implemented in the school buildings, these are low temperature heating, high temperature cooling, radiant wall and ceiling panels and thermally activated building system. The last technology is not applicable in existing buildings, according to the literature. All other technologies can be technically applied in new and existing school buildings. In total 23 energy efficient technologies have been discussed.

The energy consumption pattern is determined in this study by using the energy consumption of ten school buildings. These are both primary and secondary school buildings. From the energy consumption pattern can be observed that the school buildings consume their main energy from 7 o'clock in the morning to 8 o'clock in the evening. This finding proves also that solar energy is useful to implement in school buildings, because the energy generation of solar panels is also during the day. In the energy consumption pattern can be seen that the outdoor temperature, the amount of pupils, the application of solar panels and the implementation of a cooling system are influencing factors on the energy consumption of school buildings.

In the panel data analysis, also other influencing factors on the energy consumption of school buildings are determined in this research. Education time and the EPC value are likely to be the most influencing factors on the energy consumption of school buildings. The amount of PV panels is inclined to be the least influencing factor.

Remarkable is that results show that the higher the EPC value, the less energy is consumed. This is a contradiction, because the lower the EPC value, the higher the level of energy efficiency of a building. Also remarkable is that one of the models shows that if more PV panels are installed, more energy is consumed. It is assumed that these contradictions are caused by school 5. This school has the highest share of PV panels and a low EPC value, but this school also consumes the most energy. Excluding school 5 in the model causes that the sample size is too small to improve the model estimation. In this analysis a small sample size of only 10 schools is included. The data includes independent variables with less variation and much correlations. This can also cause the contradictions in the estimated model.

The school building user preferences on these energy efficient technologies are determined in this study by means of a stated choice experiment. The technologies implemented in the questionnaire are heating system, ventilation system, lighting, PV panels and sun blinds. In the questionnaire the energy efficient technology and the conventional technology is included. Except for PV panels, here is chosen between PV panels or no PV panels. Based on the advantages and disadvantages of the technologies the choices are included. For example for PV panels a disadvantage can be that classrooms might be less warm in comparison with no PV panels. Respondents might make their choices based on the room temperature instead of the technology. This must be noted while interpreting the results.

Results show that ventilation system is for both pupils and teachers the most influencing factor on the choice of a class room. For the ventilation system, the energy efficient system is chosen above the conventional system. This also account for the type of heating system. For lighting system and sun blinds, both the pupil and teachers are likely to choose the conventional system above the energy efficient system. For PV panels, the teachers are slightly likely to choose to have PV panels while pupils prefer not having solar panels. In this research is proved that the teachers in this questionnaire are more likely to be energy conscious in comparison with pupils. Both teachers and pupils show large differences in preferences.

6.2. Recommendations and future research

To give a more complete advice to school boards and directors about the implementation of the energy efficient technologies, also the financial aspects of these systems must be take into account, based on this statement follow-up research can therefore be conducted.

To give a more specific judgement about the influencing factors on the energy consumption of school buildings and also the excluded variables of this study, more school buildings must be investigated. In this way these excluded variables can also be taken into consideration.

To indicate the user preferences on the energy efficient technologies, a questionnaire is developed in which 6 of these technologies are implemented. To indicate the user preference on all 23 energy efficient technologies, further research must be conducted.

6.3. Managerial implications

This research proved that teachers are likely to choose conventional systems for lighting and sun blinds above the energy efficient technology (based on the advantages and disadvantages of these technologies). This also accounts for pupils, but pupils also prefer to not choose PV panels instead of choosing PV panels. School boards can advise their schools to provide more information of the advantages of PV panels to pupils. Especially when constructing a new school building after the end of 2020, because then the requirements for NZEB apply to educational buildings.

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APPENDICES

APPENDIX A. PRO'S & CON'S ENERGY EFFICIENT TECHNOLOGIES

HEATING/COOLING

2.1.1 Radiant ceiling/wall panels
+ energy efficient
+ pleasant indoor climate.
+ less draught
+ ensures more comfort
+ little to no noise
+ suitable for low temperature heating and high temperature cooling
+ system can be equipped with several features, such as ventilation and acoustic solutions
- higher capital costs than convective systems
- Installation and adjustment must be done carefully
- difficult to check the system and to approach the remaining installations in the ceiling after installation
- condensation can occur

2.1.2 Thermally activated building systems (TABS)
+ provide a high level of comfort
+ less affection of draughts
+ minimum of noise disturbance
+ energy efficient with the aid of low temperature heating (LTH) and high temperature cooling (HTC)
+ investment costs of thermally activated building systems are low in comparison with traditional systems, this also applies to the running costs of TABS
+ If this system is combined with a geothermal heat pump, the system is called GEOTABS, a very energy efficient solution (Kosonen, 2017; Rhee, Olesen & Kim, 2017).
+ TABS are delivering heat/cold radiation both up via the floor and down via the ceiling
- building must be insulated very well, otherwise heat losses arise
- two spaces located one above the other, have a different heat demand
- Heating and cooling for individual spaces is also an issue
- extra attention must be drawn to the design, when developing a building with TABS, both for the layout and the acoustics.
- Acoustic facilities cannot be processed into the ceiling
- slow operation -> sometimes additional heating system is required during peak demand
- not renovation projects

2.1.3 Low temperature heating (LTH)
+ comfortable and healthy indoor environment
+ less air movement
+ environmental friendly
+ very energy efficient
- A limitation of this system is, that it is difficult to apply in renovation projects with convective heating systems

2.1.4 High temperature cooling (HTC)
+ energy efficient. When used in well isolated buildings
+ provide energy savings
+ ensures a comfortable and healthy indoor environment

2.1.5 Cogeneration or combined heat & power (CHP)
+ only one system is used for both heat and electricity
+ more efficient than central energy stations
+ The greenhouse gas emissions are lower in comparison with conventional energy generators
+ energy efficient and reduces costs
- heat and electricity generation must be adjusted, otherwise too much unnecessary energy is produced

2.1.6 Trigeneration or combined cooling, heat & power (CCHP)
+ can produce heat for heating in the winter and cooling for air-conditioning in the summer
+ saving energy costs
+ flexible
+ reducing greenhouse gas emissions
- more expensive than CHP, because of the additional absorption chiller

VENTILATION

2.2.1 Balanced heat recovery systems
+ more comfort in the building
+ reduce the amount of heat losses
+ saves energy
- building must have high thermal insulation and air tightness
- opening windows is still necessary to increase the amount of fresh air
- much higher investment costs than traditional systems
- energy savings are up against the energy usage of the ventilators of the mechanical ventilation system

2.2.2 Earth-air tube ventilation
+ reduces energy costs for heating and cooling
+ better comfort
+ very energy efficient
- can cause moisture problems through the underground tubes
- large site is required

2.2.3 Bauer Optimalisation ventilation technology
- limited scientific research

RENEWABLE ENERGY SOURCES

2.3.2.1 Horizontal ground source heat pump
+ lower installation costs than vertical systems
+ not the most expensive system
- not the highest coefficient of performance (COP)
- COP values differ between several locations
- Efficiency influenced by the pipe configuration, the type of pipe and the depth
- a large surface area is required

2.3.2.2 Vertical ground source heat pump
+ most efficient system in comparison with other heat pumps
+ only a few surface area needed
- installation costs are much higher, because of the deep boreholes
- implementation of this system is not always possible due to groundwater protection areas

2.3.2.3 Groundwater heat pump
+ high efficiency due to a constant groundwater temperature
+ operational and energy usage is lower than traditional systems
+ higher energy density, faster transport and lower costs, in comparison with other ground source heat pumps
- it is not applicable at any location, because it requires an aquifer
- temperature difference between the pumped water and the re-injected water can influence the performances of other heat pumps in the neighborhood

2.3.3.1 Air to air heat pump
+ simple to install, also for the other air source heat pumps
+ high energy saving potential
+ efficient solution
+ more comfortable
+ more quickly warmed up
- 70% less efficient in cold temperature climates than in warm temperature climates

2.3.3.2 Air to water heat pump
+ simple to install, also for the other air source heat pumps
+ high energy saving potential
+ efficient solution
- 70% less efficient in cold temperature climates than in warm temperature climates

2.3.3.3 Heat pump water heater
+ lower implementation costs than other heat pump boilers
+ less complex system
- Higher initial costs in comparison with other water heating systems
- not able to heat water on high demand

2.3.4.1 Photovoltaic (PV) panels
+ efficiency
+ energy saving potential.
+ cells are warranted for 25 years
- efficiency depends on the performance of the materials.
- the less expensive, the less efficient

2.3.4.2 Photovoltaic (PV) glazing
+ electricity generation
+ blocking sunlight
+ cooling loads are reduced what maintains into energy savings for air conditioning
+ useful in renovation projects, because of the simple installation and replacement of traditional glazing
- it provides less visibility to the external environment
- expensive technology due to the high initial costs of silicon PV cells
- the integration of the PV windows must be extensively investigated in both new and existing buildings due to the building energy balance

2.3.4.3 Solar water heater
+ simplest technique of all the solar energy technologies
+ the most affordable of all the solar energy technologies
+ potential to save up to 38% of the energy supply
- mainly used for small-size consumption
- must have access to a large storage tank
- various payback time of this system through different countries
- very affordable in the South of Europe, due to the warm climate

2.3.5.1 Micro-wind turbine
+ generates electricity in a usable form
+ provides a high degree of technical reliability
+ Linked to a battery storage system, micro-wind turbines can supply continuous power generation
- high levels of noise generated by the turbines
- limited performance in urban areas
- the higher the density in urban areas the lower the electricity generation
- mainly applied in rural areas or off-grid systems

TECHNOLOGIES ENERGY STORAGE

2.4.1 Thermal energy storage
+ an efficient method for energy storage
+ a better life cycle
+ more durable
+ also able to storage energy directly, because it does not have to be converted in another form of energy
- mainly used for high consumption purposes
- in comparison with batteries, less suitable for energy storage from wind and solar energy sources

2.4.2 Battery energy storage
+ less generated energy is being wasted
+ less energy costs during peak hours
+ there will be used more and more efficient cleaner energy
- technology is uncertain and challenging, due to the capacities, energy yields and investment costs
- batteries are made of toxicities and these materials are not sustainable

2.4.3 Smart grid
+ cost minimization and energy-efficiency
- creates uncertainty for the consumers and it is a source of energy losses before reaching the end-user
- Also the smart grid must be available at the location, or else a grid must first be implemented

TECHNOLOGIES BUILDING AUTOMATION

2.5.1 Automatic lighting
+ reduces energy consumption
+ saves energy costs
+ can save up to 38% of energy in comparison with manual lighting systems
- if someone is out of reach of the motion sensors or is not moving, the lights will be switched off

2.5.2 Automatic sun blinds
+ savings on cooling load, because of automatic shading, more warmth of the sunlight is blocked.
+ less energy consumption of the cooling system
- occupants are annoyed if the sun blinds are lowered if it still feels glary, and otherwise if it feels bright

2.5.3 Automatic daylight control
+ saves the energy consumption
+ more energy efficient
+ provides occupant comfort

APPENDIX B. RESULT TABLES EFFECT CODING

Season of the year

	Se1	*Se2*	*Se3*
Spring	1	0	0
Summer	0	1	0
Autumn	0	0	1
Winter	-1	-1	-1

Day of the week

	Day1	*Day2*	*Day3*	*Day4*	*Day5*	*Day6*
Monday	1	0	0	0	0	0
Tuesday	0	1	0	0	0	0
Wednesday	0	0	1	0	0	0
Thursday	0	0	0	1	0	0
Friday	0	0	0	0	1	0
Saturday	0	0	0	0	0	1
Sunday	-1	-1	-1	-1	-1	-1

Part of the day

	Dp1	*Dp2*	*Dp3*
Morning	1	0	0
Afternoon	0	1	0
Evening	0	0	1
Night	-1	-1	-1

Education time

	Ed1
Education time	1
No education time	-1

Vacation time

	Va1
Vacation time	1
No vacation time	-1

Type of heating system

	Heat1	*Heat2*	*Heat3*	*Heat4*	*Heat5*
Heat pump with high efficiency boiler	1	0	0	0	0
High efficiency boiler with LTH	0	1	0	0	0
Heat pump with district heating	0	0	1	0	0
District heating with LTH	0	0	0	1	0
Air handling unit	0	0	0	0	1
District heating	-1	-1	-1	-1	-1

Type of cooling system

	Cool1	*Cool2*	*Cool3*
Electric chiller with compressor	1	0	0
Ground source heat pump with HTC	0	1	0
Air source heat pump with HTC	0	0	1
No cooling system implemented	-1	-1	-1

Type of ventilation system

	Vent1	*Vent2*
Balanced heat recovery system	1	0
Mechanical ventilation (CO2 controlled)	0	1
Natural ventilation	-1	-1

Type of installations

	In1	*In2*	*In3*	*In4*	*In5*
Ground/air source heat pump with high efficiency boiler Balanced heat recovery system	1	0	0	0	0
High efficiency boiler with LTH Mechanical ventilation (CO2 controlled)	0	1	0	0	0
Central heating Mechanical ventilation (CO2 controlled)	0	0	1	0	0
Air handling unit Natural ventilation	0	0	0	1	0
Air source heat pump with high efficiency boiler Mechanical ventilation (CO2 controlled)	0	0	0	0	1
None of the above	-1	-1	-1	-1	-1

APPENDIX C. CORRELATION TABLE 1

A	B
C	D

Part A

Correlations

		Va1	Ed1	Se1	Se2	Se3	Day1	Day2	Day3	Day4	Day5	Day6	Dp1	Dp2	Dp3	Pupil	Year	Area	Layer	Rarea
Va1	Pearson Corr.	1	-,260**	-,078**	,169**	-,130**	-,058**	-,058**	-,058**	-,059**	-,059**	-,002	,000	,000	,000	,005	-,012**	,007*	,006	,006
	Sig. (2-tailed)		0,000	,000	0,000	0,000	,000	,000	,000	,000	,000	,463	1,000	1,000	1,000	,118	,000	,020	,060	,064
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Ed1	Pearson Corr.	-,260**	1	,018**	-,045**	,027**	,170**	,171**	,141**	,170**	,169**	-,002	,350**	,272**	,000	,054**	-,017**	,048**	,054**	,049**
	Sig. (2-tailed)	0,000		,000	,000	,000	0,000	0,000	0,000	0,000	0,000	,584	0,000	0,000	1,000	,000	,000	,000	,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Se1	Pearson Corr.	-,078**	,018**	1	,490**	,503**	,002	,010**	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000
	Sig. (2-tailed)	,000	,000		0,000	0,000	,433	,002	,999	,996	,996	,994	1,000	1,000	1,000	,905	,909	,974	,890	,999
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Se2	Pearson Corr.	,169**	-,045**	,490**	1	,497**	,001	,008*	,005	-,001	,000	,000	,000	,000	,000	-,015**	,022**	-,005	-,011**	-,004
	Sig. (2-tailed)	0,000	,000	0,000		0,000	,849	,012	,081	,834	,985	,977	1,000	1,000	1,000	,000	,000	,092	,000	,228
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Se3	Pearson Corr.	-,130**	,027**	,503**	,497**	1	-,002	,002	-,005	,004	,004	,006	,000	,000	,000	-,024**	,067**	-,022**	-,031**	-,011**
	Sig. (2-tailed)	0,000	,000	0,000	0,000		,427	,424	,111	,229	,228	,071	1,000	1,000	1,000	,000	,000	,000	,000	,001
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day1	Pearson Corr.	-,058**	,170**	,002	,001	-,002	1	,500**	,500**	,499**	,499**	,498**	,000	,000	,000	,000	,001	,000	,000	,000
	Sig. (2-tailed)	,000	0,000	,433	,849	,427		0,000	0,000	0,000	0,000	0,000	1,000	1,000	1,000	,899	,846	,994	,924	,975
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day2	Pearson Corr.	-,058**	,171**	,010**	,008*	,002	,500**	1	,500**	,499**	,499**	,498**	,000	,000	,000	,000	,001	,000	,000	,000
	Sig. (2-tailed)	,000	0,000	,002	,012	,424	0,000		0,000	0,000	0,000	0,000	1,000	1,000	1,000	,899	,846	,994	,924	,975
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day3	Pearson Corr.	-,058**	,141**	,000	,005	-,005	,500**	,500**	1	,499**	,499**	,498**	,000	,000	,000	,000	,001	,000	,000	,000
	Sig. (2-tailed)	,000	0,000	,999	,081	,111	0,000	0,000		0,000	0,000	0,000	1,000	1,000	1,000	,899	,846	,994	,924	,975
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day4	Pearson Corr.	-,059**	,170**	,000	-,001	,004	,499**	,499**	,499**	1	,498**	,497**	,000	,000	,000	,000	-,002	,000	,000	,000
	Sig. (2-tailed)	,000	0,000	,996	,834	,229	0,000	0,000	0,000		0,000	0,000	1,000	1,000	1,000	,932	,625	,879	,905	,931
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day5	Pearson Corr.	-,059**	,169**	,000	,000	,004	,499**	,499**	,499**	,498**	1	,497**	,000	,000	,000	,000	-,001	,000	,000	,000
	Sig. (2-tailed)	,000	0,000	,996	,985	,228	0,000	0,000	0,000	0,000		0,000	1,000	1,000	1,000	,963	,768	,979	,980	,967
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day6	Pearson Corr.	-,002	-,002	,000	,000	,006	,498**	,498**	,498**	,497**	,497**	1	,000	,000	,000	,000	,000	,000	,000	,000
	Sig. (2-tailed)	,463	,584	,994	,977	,071	0,000	0,000	0,000	0,000	0,000		1,000	1,000	1,000	,983	,883	,908	,970	,884
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Dp1	Pearson Corr.	,000	,350**	,000	,000	,000	,000	,000	,000	,000	,000	,000	1	,500**	,500**	,000	,000	,000	,000	,000
	Sig. (2-tailed)	1,000	0,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000		0,000	0,000	1,000	1,000	1,000	1,000	1,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Dp2	Pearson Corr.	,000	,272**	,000	,000	,000	,000	,000	,000	,000	,000	,000	,500**	1	,500**	,000	,000	,000	,000	,000
	Sig. (2-tailed)	1,000	0,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	0,000		0,000	1,000	1,000	1,000	1,000	1,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Dp3	Pearson Corr.	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,500**	,500**	1	,000	,000	,000	,000	,000
	Sig. (2-tailed)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	0,000	0,000		1,000	1,000	1,000	1,000	1,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Pupil	Pearson Corr.	,005	,054**	,000	-,015**	-,024**	,000	,000	,000	,000	,000	,000	,000	,000	,000	1	-,144**	,906**	,962**	,940**
	Sig. (2-tailed)	,118	,000	,905	,000	,000	,899	,899	,899	,932	,963	,983	1,000	1,000	1,000		0,000	0,000	0,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Year	Pearson Corr.	-,012**	-,017**	,000	,022**	,067**	,001	,001	,001	-,002	-,001	,000	,000	,000	,000	-,144**	1	-,257**	-,250**	-,082**
	Sig. (2-tailed)	,000	,000	,909	,000	,000	,846	,846	,846	,625	,768	,883	1,000	1,000	1,000	0,000		0,000	0,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Area	Pearson Corr.	,007*	,048**	,000	-,005	-,022**	,000	,000	,000	,000	,000	,000	,000	,000	,000	,906**	-,257**	1	,936**	,937**
	Sig. (2-tailed)	,020	,000	,974	,092	,000	,994	,994	,994	,879	,979	,908	1,000	1,000	1,000	0,000	0,000		0,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Layer	Pearson Corr.	,006	,054**	,000	-,011**	-,031**	,000	,000	,000	,000	,000	,000	,000	,000	,000	,962**	-,250**	,936**	1	,911**
	Sig. (2-tailed)	,060	,000	,890	,000	,000	,924	,924	,924	,905	,980	,970	1,000	1,000	1,000	0,000	0,000	0,000		0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Rarea	Pearson Corr.	,006	,049**	,000	-,004	-,011**	,000	,000	,000	,000	,000	,000	,000	,000	,000	,940**	-,082**	,937**	,911**	1
	Sig. (2-tailed)	,064	,000	,999	,228	,001	,975	,975	,975	,931	,967	,884	1,000	1,000	1,000	0,000	,000	0,000	0,000	
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

A	B
C	D

Part B

Correlations

Fac	Flo	Roo	Win	EPC	Heat1	Heat2	Heat3	Heat4	Heat5	Cool1	Cool2	Cool3	Vent1	Vent2	PV	Pro	Tem	Sun		
-,002	,002	-,027**	-,008*	,013**	,000	,000	,008*	,000	-,011**	,001	,001	,001	-,001	,000	,009**	,015**	,120**	,012**	Va1	Pearson Corr.
,532	,627	,000	,016	,000	,904	,954	,010	,997	,000	,691	,710	,664	,829	,948	,002	,000	0,000	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,021**	,036**	,011**	,018**	,032**	-,015**	-,030**	-,031**	-,027**	-,027**	-,022**	-,015**	,007*	-,018**	-,032**	,015**	,140**	,121**	,270**	Ed1	Pearson Corr.
,000	,000	,001	,000	,000	,000	,000	,000	,000	,000	,000	,000	,026	,000	,000	,000	0,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,000	,000	,001	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,001	,113**	,422**	,172**	Se1	Pearson Corr.
,921	,885	,765	,966	,947	,905	,972	,981	,895	,980	,995	,984	,926	,968	,949	,745	,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,041**	-,002	-,055**	-,032**	,030**	-,004	-,005	,035**	,004	,025**	-,024**	-,024**	-,024**	,014**	-,002	-,006	,088**	,668**	,133**	Se2	Pearson Corr.
,000	,588	,000	,000	,000	,205	,155	,000	,272	,000	,000	,000	,000	,000	,497	,062	,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,009**	-,001	,006	-,001	-,046**	-,001	-,001	,002	,001	,011**	-,005	-,005	-,005	,003	,000	-,055**	,000	,219**	,021**	Se3	Pearson Corr.
,007	,839	,072	,641	,000	,873	,753	,597	,744	,001	,124	,133	,146	,344	,932	,000	,993	0,000	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,001	,000	-,003	-,001	,001	,000	,000	,001	,000	,000	-,001	-,001	-,001	,000	,000	,000	-,003	,004	-,005	Day1	Pearson Corr.
,737	1,000	,377	,697	,736	,971	,971	,671	,980	,950	,842	,848	,841	,907	,985	,943	,412	,256	,082		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,001	,000	-,003	-,001	,001	,000	,000	,001	,000	,000	-,001	-,001	-,001	,000	,000	,000	-,006	,002	-,027**	Day2	Pearson Corr.
,737	1,000	,377	,697	,736	,971	,971	,671	,980	,950	,842	,848	,841	,907	,985	,943	,096	,613	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,001	,000	-,003	-,001	,001	,000	,000	,001	,000	,000	-,001	-,001	-,001	,000	,000	,000	-,005	,007*	-,022**	Day3	Pearson Corr.
,737	1,000	,377	,697	,736	,971	,971	,671	,980	,950	,842	,848	,841	,907	,985	,943	,119	,016	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
-,001	-,001	-,001	,000	,001	,000	,000	,000	-,001	,000	,000	,000	,000	,000	,000	,000	-,005	,008**	-,021**	Day4	Pearson Corr.
,809	,856	,784	,897	,776	,885	,954	,910	,857	,910	,953	,929	,956	,927	,938	,923	,170	,008	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,000	-,001	,000	,000	,001	-,001	,000	,000	,000	,001	,000	,000	-,001	,000	,000	,000	-,007*	-,002	-,038**	Day5	Pearson Corr.
,925	,821	,943	,938	,689	,857	,983	,959	,877	,756	,888	,919	,799	,980	,923	,952	,027	,482	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,002	,000	,002	,000	,001	,000	,000	,000	,001	,002	-,001	-,001	,000	,001	,000	,001	-,009**	-,003	-,039**	Day6	Pearson Corr.
,603	,889	,592	,885	,854	,909	,930	,893	,840	,619	,822	,804	,912	,850	,951	,749	,006	,372	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,120**	,175**	,346**	Dp1	Pearson Corr.
1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,195**	,252**	,339**	Dp2	Pearson Corr.
1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	0,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,013**	,069**	-,007*	Dp3	Pearson Corr.
1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	,000	,000	,019		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,347**	,667**	,096**	,355**	,529**	-,244**	-,623**	-,614**	-,624**	-,614**	-,526**	-,312**	,063**	-,451**	-,548**	,034**	,055**	-,008**	,001	Pupil	Pearson Corr.
0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	0,000	0,000	,000	,000	,009	,752		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,661**	,682**	,706**	-,423**	-,567**	,419**	-,154**	,317**	,427**	,316**	-,168**	-,208**	,275**	,286**	,163**	-,434**	-,199**	-,010**	-,006	Year	Pearson Corr.
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,001	,061		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,278**	,289**	-,153**	,673**	,410**	-,505**	-,800**	-,840**	-,791**	-,859**	-,653**	-,396**	-,279**	-,729**	-,666**	-,003	-,013**	,005	,002	Area	Pearson Corr.
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,325	,000	,123	,478		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,492**	,517**	,092**	,541**	,519**	-,437**	-,721**	-,757**	-,685**	-,757**	-,600**	-,507**	-,146**	-,557**	-,691**	,179**	,106**	-,005	,002	Layer	Pearson Corr.
0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,089	,558		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,308**	,496**	-,133**	,487**	,394**	-,468**	-,603**	-,705**	-,706**	-,726**	-,455**	-,339**	-,026**	-,482**	-,714**	-,161**	-,117**	,004	,001	Rarea	Pearson Corr.
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	,000	,238	,689		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

A	B
C	D

Part C

		Va1	Ed1	Se1	Se2	Se3	Day1	Day2	Day3	Day4	Day5	Day6	Dp1	Dp2	Dp3	Pupil	Year	Area	Layer	Rarea
Fac	Pearson Corr.	-,002	,021**	,000	,041**	,009**	,001	,001	,001	-,001	,000	,002	,000	,000	,000	,347**	,661**	,278**	,492**	,308**
	Sig. (2-tailed)	,532	,000	,921	,000	,007	,737	,737	,737	,809	,925	,603	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Flo	Pearson Corr.	,002	,036**	,000	-,002	-,001	,000	,000	,000	-,001	-,001	,000	,000	,000	,000	,667**	,682**	,289**	,517**	,496**
	Sig. (2-tailed)	,627	,000	,885	,588	,839	1,000	1,000	1,000	,856	,821	,889	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176
Roo	Pearson Corr.	-,027**	,011**	,001	-,055**	,006	-,003	-,003	-,003	-,001	,000	,002	,000	,000	,000	,096**	,706**	-,153**	,092**	-,133**
	Sig. (2-tailed)	,000	,001	,765	,000	,072	,377	,377	,377	,784	,943	,592	1,000	1,000	1,000	,000	0,000	0,000	,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Win	Pearson Corr.	-,008*	,018**	,000	-,032**	-,001	-,001	-,001	-,001	,000	,000	,000	,000	,000	,000	,355**	-,423**	,673**	,541**	,487**
	Sig. (2-tailed)	,016	,000	,966	,000	,641	,697	,697	,697	,897	,938	,885	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
EPC	Pearson Corr.	,013**	,032**	,000	,030**	-,046**	,001	,001	,001	,001	,001	,001	,000	,000	,000	,529**	-,567**	,410**	,519**	,394**
	Sig. (2-tailed)	,000	,000	,947	,000	,000	,736	,736	,736	,776	,689	,854	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Heat1	Pearson Corr.	,000	-,015**	,000	-,004	-,001	,000	,000	,000	,000	-,001	,000	,000	,000	,000	-,244**	,419**	-,505**	-,437**	-,468**
	Sig. (2-tailed)	,904	,000	,905	,205	,873	,971	,971	,971	,885	,857	,909	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Heat2	Pearson Corr.	,000	-,030**	,000	-,005	-,001	,000	,000	,000	,000	,000	,000	,000	,000	,000	-,623**	-,154**	-,800**	-,721**	-,603**
	Sig. (2-tailed)	,954	,000	,972	,155	,753	,971	,971	,971	,954	,983	,930	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Heat3	Pearson Corr.	,008*	-,031**	,000	,035**	,002	,001	,001	,001	,000	,000	,000	,000	,000	,000	-,614**	,317**	-,840**	-,757**	-,705**
	Sig. (2-tailed)	,010	,000	,981	,000	,597	,671	,671	,671	,910	,959	,893	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Heat4	Pearson Corr.	,000	-,027**	,000	,004	,001	,000	,000	,000	-,001	,000	,001	,000	,000	,000	-,624**	,427**	-,791**	-,685**	-,706**
	Sig. (2-tailed)	,997	,000	,895	,272	,744	,980	,980	,980	,857	,877	,840	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Heat5	Pearson Corr.	-,011**	-,027**	,000	,025**	,011**	,000	,000	,000	,000	,001	,002	,000	,000	,000	-,614**	,316**	-,859**	-,757**	-,726**
	Sig. (2-tailed)	,000	,000	,980	,000	,001	,950	,950	,950	,910	,756	,619	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Cool1	Pearson Corr.	,001	-,022**	,000	-,024**	-,005	-,001	-,001	-,001	,000	,000	-,001	,000	,000	,000	-,526**	-,168**	-,653**	-,600**	-,455**
	Sig. (2-tailed)	,691	,000	,995	,000	,124	,842	,842	,842	,953	,888	,822	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Cool2	Pearson Corr.	,001	-,015**	,000	-,024**	-,005	-,001	-,001	-,001	,000	,000	-,001	,000	,000	,000	-,312**	-,208**	-,396**	-,507**	-,339**
	Sig. (2-tailed)	,710	,000	,984	,000	,133	,848	,848	,848	,929	,919	,804	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Cool3	Pearson Corr.	,001	,007*	,000	-,024**	-,005	-,001	-,001	-,001	,000	-,001	,000	,000	,000	,000	,063**	,275**	-,279**	-,146**	-,026**
	Sig. (2-tailed)	,664	,026	,926	,000	,146	,841	,841	,841	,956	,799	,912	1,000	1,000	1,000	,000	0,000	0,000	0,000	,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Vent1	Pearson Corr.	-,001	-,018**	,000	,014**	,003	,000	,000	,000	,000	,000	,001	,000	,000	,000	-,451**	,286**	-,729**	-,557**	-,482**
	Sig. (2-tailed)	,829	,000	,968	,000	,344	,907	,907	,907	,927	,980	,850	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Vent2	Pearson Corr.	,000	-,032**	,000	-,002	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	-,548**	,163**	-,666**	-,691**	-,714**
	Sig. (2-tailed)	,948	,000	,949	,497	,932	,985	,985	,985	,938	,923	,951	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
PV	Pearson Corr.	,009**	,015**	,001	-,006	-,055**	,000	,000	,000	,000	,000	,001	,000	,000	,000	,034**	-,434**	-,003	,179**	-,161**
	Sig. (2-tailed)	,002	,000	,745	,062	,000	,943	,943	,943	,923	,952	,749	1,000	1,000	1,000	,000	0,000	,325	0,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Pro	Pearson Corr.	,015**	,140**	,113**	,088**	,000	-,003	-,006	-,005	-,005	-,007*	-,009**	,120**	,195**	,013**	,055**	-,199**	-,013**	,106**	-,117**
	Sig. (2-tailed)	,000	0,000	,000	,000	,993	,412	,096	,119	,170	,027	,006	,000	0,000	,000	,000	0,000	,000	,000	,000
	N	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504
Tem	Pearson Corr.	,120**	,121**	,422**	,668**	,219**	,004	,002	,007*	,008**	-,002	-,003	,175**	,252**	,069**	-,008**	-,010**	,005	-,005	,004
	Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	,256	,613	,016	,008	,482	,372	0,000	0,000	,000	,009	,001	,123	,089	,238
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Sun	Pearson Corr.	,012**	,270**	,172**	,133**	,021**	-,005	-,027**	-,022**	-,021**	-,038**	-,039**	,346**	,339**	-,007*	,001	-,006	,002	,002	,001
	Sig. (2-tailed)	,000	0,000	0,000	0,000	,000	,082	,000	,000	,000	,000	,000	0,000	0,000	,019	,752	,061	,478	,558	,689
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

A	B
C	D

Part D

1	,323**	,435**	,221**	,036**	-,360**	-,360**	-,282**	-,080**	-,283**	-,347**	-,829**	-,284**	-,057**	-,520**	,448**	,227**	,001	,000	Fac	Pearson Corr.
	0,000	0,000	0,000	,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	,648	,991		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,323**	1	,507**	-,427**	,435**	,362**	-,080**	,148**	,056**	,137**	-,065**	,046**	,648**	,258**	-,043**	-,025**	,045**	-,018**	-,002	Flo	Pearson Corr.
0,000		0,000	0,000	0,000	0,000	,000	0,000	,000	0,000	,000	,000	0,000	0,000	,000	,000	,000	,000	,631		Sig. (2-tailed)
97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	79488	97176	97176		N
,435**	,507**	1	-,151**	-,348**	,355**	-,120**	,098**	,415**	,242**	-,059**	-,134**	,211**	,170**	,190**	,632**	,369**	-,061**	-,008*	Roo	Pearson Corr.
0,000	0,000		0,000	0,000	0,000	0,000	,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,016		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,221**	-,427**	-,151**	1	-,175**	-,802**	-,683**	-,950**	-,679**	-,906**	-,501**	-,544**	-,720**	-,800**	-,684**	-,048**	-,089**	-,007*	-,001	Win	Pearson Corr.
0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,000	,022	,689		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,036**	,435**	-,348**	-,175**	1	,074**	,029**	-,057**	-,589**	-,097**	-,342**	-,205**	,023**	-,105**	-,096**	,098**	,324**	,027**	,007*	EPC	Pearson Corr.
,000	0,000	0,000	0,000		,000	,000	,000	0,000	,000	0,000	0,000	,000	,000	,000	,000	0,000	,000	,032		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
-,360**	,362**	,355**	-,802**	,074**	1	,291**	,744**	,538**	,745**	,101**	,602**	,520**	,369**	,916**	,078**	,213**	-,016**	-,001	Heat1	Pearson Corr.
0,000	0,000	0,000	0,000	,000		0,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	,000	0,000	,000	,652		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,360**	-,080**	-,120**	-,683**	,029**	,291**	1	,744**	,538**	,745**	,852**	,414**	,520**	,860**	,346**	-,113**	-,050**	,003	,000	Heat2	Pearson Corr.
0,000	,000	0,000	0,000	,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,000	,394	,935		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,282**	,148**	,098**	-,950**	-,057**	,744**	,744**	1	,809**	,952**	,600**	,576**	,602**	,822**	,739**	,194**	,086**	,011**	,002	Heat3	Pearson Corr.
0,000	0,000	,000	0,000	,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,001	,610		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,080**	,056**	,415**	-,679**	-,589**	,538**	,538**	,809**	1	,810**	,661**	,495**	,547**	,769**	,553**	,685**	,094**	-,015**	-,001	Heat4	Pearson Corr.
,000	,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,000	,669		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,283**	,137**	,242**	-,906**	-,097**	,745**	,745**	,952**	,810**	1	,601**	,578**	,603**	,822**	,740**	,201**	,094**	,003	-,001	Heat5	Pearson Corr.
0,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	,000	,388	,866		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,347**	-,065**	-,059**	-,501**	-,342**	,101**	,852**	,600**	,661**	,601**	1	,533**	,649**	,853**	,135**	,155**	-,217**	-,009**	-,001	Cool1	Pearson Corr.
0,000	,000	,000	0,000	0,000	,000	0,000	0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	,007	,818		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,829**	,046**	-,134**	-,544**	-,205**	,602**	,414**	,576**	,495**	,578**	,533**	1	,676**	,393**	,624**	-,087**	-,205**	-,005	,000	Cool2	Pearson Corr.
0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	0,000	,000	0,000	,097	,893		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,284**	,648**	,211**	-,720**	,023**	,520**	,520**	,602**	,547**	,603**	,649**	,676**	1	,732**	,279**	,026**	-,224**	-,019**	-,002	Cool3	Pearson Corr.
0,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	,000	0,000	,000	,594		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,057**	,258**	,170**	-,800**	-,105**	,369**	,860**	,822**	,769**	,822**	,853**	,393**	,732**	1	,286**	,232**	-,047**	,000	,000	Vent1	Pearson Corr.
,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	,000	,950	,987		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
-,520**	-,043**	,190**	-,684**	-,096**	,916**	,346**	,739**	,553**	,740**	,135**	,624**	,279**	,286**	1	,094**	,209**	-,009**	-,001	Vent2	Pearson Corr.
0,000	,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		,000	0,000	,008	,809		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,448**	-,025**	,632**	-,048**	,098**	,078**	-,113**	,194**	,685**	,201**	,155**	-,087**	,026**	,232**	,094**	1	,418**	-,013**	,003	PV	Pearson Corr.
0,000	,000	0,000	,000	,000	,000	,000	0,000	0,000	0,000	0,000	,000	,000	0,000	,000		0,000	,000	,332		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,227**	,045**	,369**	-,089**	,324**	,213**	-,050**	,086**	,094**	,094**	-,217**	-,205**	-,224**	-,047**	,209**	,418**	1	,209**	,237**	Pro	Pearson Corr.
0,000	,000	0,000	,000	0,000	0,000	,000	,000	,000	,000	0,000	0,000	0,000	,000	0,000	0,000		0,000	0,000		Sig. (2-tailed)
80232	79488	80232	80232	87504	80232	80232	80232	80232	80232	80232	80232	80232	80232	80232	87504	87504	87504	87504		N
,001	-,018**	-,061**	-,007*	,027**	-,016**	,003	,011**	-,015**	,003	-,009**	-,005	-,019**	,000	-,009**	-,013**	,209**	1	,370**	Tem	Pearson Corr.
,648	,000	,000	,022	,000	,000	,394	,001	,000	,388	,007	,097	,000	,950	,008	,000	0,000		0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
,000	-,002	-,008*	-,001	,007*	-,001	,000	,002	-,001	-,001	-,001	,000	-,002	,000	-,001	,003	,237**	,370**	1	Sun	Pearson Corr.
,991	,631	,016	,689	,032	,652	,935	,610	,669	,866	,818	,893	,594	,987	,809	,332	0,000	0,000			Sig. (2-tailed)
97920	97176	97920	97920	105216	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	105216	87504	105216	105216		N
Fac	Flo	Roo	Win	EPC	Heat1	Heat2	Heat3	Heat4	Heat5	Cool1	Cool2	Cool3	Vent1	Vent2	PV	Pro	Tem	Sun		

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

APPENDIX D. CORRELATION TABLE 2

A	B
C	D

Part A

Correlations

		Va1	Ed1	Se1	Se2	Se3	Day1	Day2	Day3	Day4	Day5	Day6	Dp1	Dp2	Dp3	Apup
Va1	Pearson Corr.	1	-,260**	-,078**	,169**	-,130**	-,058**	-,058**	-,058**	-,059**	-,059**	-,002	,000	,000	,000	,021**
	Sig. (2-tailed)		0,000	,000	0,000	0,000	,000	,000	,000	,000	,000	,463	1,000	1,000	1,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Ed1	Pearson Corr.	-,260**	1	,018**	-,045**	,027**	,170**	,171**	,141**	,170**	,169**	-,002	,350**	,272**	,000	-,004
	Sig. (2-tailed)	0,000		,000	,000	,000	0,000	0,000	0,000	0,000	0,000	,584	0,000	0,000	1,000	,162
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Se1	Pearson Corr.	-,078**	,018**	1	,490**	,503**	,002	,010**	,000	,000	,000	,000	,000	,000	,000	-,001
	Sig. (2-tailed)	,000	,000		0,000	0,000	,433	,002	,999	,996	,996	,994	1,000	1,000	1,000	,844
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Se2	Pearson Corr.	,169**	-,045**	,490**	1	,497**	,001	,008*	,005	-,001	,000	,000	,000	,000	,000	,071**
	Sig. (2-tailed)	0,000	,000	0,000		0,000	,849	,012	,081	,834	,985	,977	1,000	1,000	1,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Se3	Pearson Corr.	-,130**	,027**	,503**	,497**	1	-,002	,002	-,005	,004	,004	,006	0,000	0,000	0,000	,005
	Sig. (2-tailed)	0,000	,000	0,000	0,000		,427	,424	,111	,229	,228	,071	1,000	1,000	1,000	,142
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day1	Pearson Corr.	-,058**	,170**	,002	,001	-,002	1	,500**	,500**	,499**	,499**	,498**	0,000	0,000	0,000	,003
	Sig. (2-tailed)	,000	0,000	,433	,849	,427		0,000	0,000	0,000	0,000	0,000	1,000	1,000	1,000	,323
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day2	Pearson Corr.	-,058**	,171**	,010**	,008*	,002	,500**	1	,500**	,499**	,499**	,498**	0,000	0,000	0,000	,003
	Sig. (2-tailed)	,000	0,000	,002	,012	,424	0,000		0,000	0,000	0,000	0,000	1,000	1,000	1,000	,323
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day3	Pearson Corr.	-,058**	,141**	,000	,005	-,005	,500**	,500**	1	,499**	,499**	,498**	0,000	0,000	0,000	,003
	Sig. (2-tailed)	,000	0,000	,999	,081	,111	0,000	0,000		0,000	0,000	0,000	1,000	1,000	1,000	,323
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day4	Pearson Corr.	-,059**	,170**	,000	-,001	,004	,499**	,499**	,499**	1	,498**	,497**	0,000	0,000	0,000	,000
	Sig. (2-tailed)	,000	0,000	,996	,834	,229	0,000	0,000	0,000		0,000	0,000	1,000	1,000	1,000	,961
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day5	Pearson Corr.	-,059**	,169**	,000	,000	,004	,499**	,499**	,499**	,498**	1	,497**	0,000	0,000	0,000	,000
	Sig. (2-tailed)	,000	0,000	,996	,985	,228	0,000	0,000	0,000	0,000		0,000	1,000	1,000	1,000	,939
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Day6	Pearson Corr.	-,002	-,002	,000	,000	,006	,498**	,498**	,498**	,497**	,497**	1	,000	,000	,000	,000
	Sig. (2-tailed)	,463	,584	,994	,977	,071	0,000	0,000	0,000	0,000	0,000		1,000	1,000	1,000	,888
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Dp1	Pearson Corr.	,000	,350**	,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	1	,500**	,500**	0,000
	Sig. (2-tailed)	1,000	0,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000		0,000	0,000	1,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Dp2	Pearson Corr.	,000	,272**	,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,500**	1	,500**	0,000
	Sig. (2-tailed)	1,000	0,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	0,000		0,000	1,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Dp3	Pearson Corr.	,000	,000	,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,500**	,500**	1	0,000
	Sig. (2-tailed)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	0,000	0,000		1,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Apup	Pearson Corr.	,021**	-,004	-,001	,071**	,005	,003	,003	,003	,000	,000	,000	0,000	0,000	0,000	1
	Sig. (2-tailed)	,000	,162	,844	,000	,142	,323	,323	,323	,961	,939	,888	1,000	1,000	1,000	
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

A	B
C	D

Part B

Correlations

Fac	Flo	Roo	Win	EPC	In1	In2	In3	In4	In5	PV	Pro	Tem	Sun		
-,002	,002	-,027**	-,008*	,013**	-,007*	-,007*	-,011**	-,008**	-,009**	,009**	,015**	,120**	,012**	Va1	Pearson Corr.
,532	,627	,000	,016	,000	,015	,015	,000	,009	,003	,002	,000	0,000	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,021**	,036**	,011**	,018**	,032**	-,033**	-,033**	-,024**	,005	,004	,015**	,140**	,121**	,270**	Ed1	Pearson Corr.
,000	,000	,001	,000	,000	,000	,000	,000	,118	,165	,000	0,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,000	,000	,001	,000	,000	,000	-,001	,000	-,001	,000	,001	,113**	,422**	,172**	Se1	Pearson Corr.
,921	,885	,765	,966	,947	,905	,816	,886	,835	,940	,745	,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,041**	-,002	-,055**	-,032**	,030**	-,006	-,008**	,038**	-,004	-,001	-,006	,088**	,668**	,133**	Se2	Pearson Corr.
,000	,588	,000	,000	,000	,057	,008	,000	,198	,793	,062	,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,009**	-,001	,006	-,001	-,046**	,043**	,042**	,058**	,045**	,052**	-,055**	,000	,219**	,021**	Se3	Pearson Corr.
,007	,839	,072	,641	,000	,000	,000	,000	,000	,000	,000	,993	0,000	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,001	0,000	-,003	-,001	,001	,000	,000	,001	,000	,000	,000	-,003	,004	-,005	Day1	Pearson Corr.
,737	1,000	,377	,697	,736	,963	,949	,740	,977	,996	,943	,412	,256	,082		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,001	0,000	-,003	-,001	,001	,000	,000	,001	,000	,000	,000	-,006	,002	-,027**	Day2	Pearson Corr.
,737	1,000	,377	,697	,736	,963	,949	,740	,977	,996	,943	,096	,613	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,001	0,000	-,003	-,001	,001	,000	,000	,001	,000	,000	,000	-,005	,007*	-,022**	Day3	Pearson Corr.
,737	1,000	,377	,697	,736	,963	,949	,740	,977	,996	,943	,119	,016	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
-,001	-,001	-,001	,000	,001	-,001	,000	-,001	,000	-,001	,000	-,005	,008**	-,021**	Day4	Pearson Corr.
,809	,856	,784	,897	,776	,815	,939	,698	,887	,704	,923	,170	,008	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,000	-,001	,000	,000	,001	-,001	,000	,000	-,001	-,001	,000	-,007*	-,002	-,038**	Day5	Pearson Corr.
,925	,821	,943	,938	,689	,779	,888	,955	,865	,701	,952	,027	,482	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,002	,000	,002	,000	,001	,000	-,001	,001	-,001	,000	,001	-,009**	-,003	-,039**	Day6	Pearson Corr.
,603	,889	,592	,885	,854	,872	,741	,799	,799	,965	,749	,006	,372	,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
0,000	0,000	,000	,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,120**	,175**	,346**	Dp1	Pearson Corr.
1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
0,000	0,000	,000	,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,195**	,252**	,339**	Dp2	Pearson Corr.
1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	0,000	0,000	0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
0,000	0,000	,000	,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,013**	,069**	-,007*	Dp3	Pearson Corr.
1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	,000	,000	,019		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
-,049**	-,498**	-,558**	,361**	-,236**	,047**	-,249**	,373**	,322**	-,250**	,044**	-,189**	,050**	,006	Apup	Pearson Corr.
,000	0,000	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	,000	0,000	,000	,052		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

A	B
C	D

Part C

Fac	Pearson Corr.	-,002	,021**	,000	,041**	,009**	,001	,001	,001	-,001	,000	,002	0,000	0,000	0,000	-,049**
	Sig. (2-tailed)	,532	,000	,921	,000	,007	,737	,737	,737	,809	,925	,603	1,000	1,000	1,000	,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Flo	Pearson Corr.	,002	,036**	,000	-,002	-,001	0,000	0,000	0,000	-,001	-,001	,000	0,000	0,000	0,000	-,498**
	Sig. (2-tailed)	,627	,000	,885	,588	,839	1,000	1,000	1,000	,856	,821	,889	1,000	1,000	1,000	0,000
	N	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176
Roo	Pearson Corr.	-,027**	,011**	,001	-,055**	,006	-,003	-,003	-,003	-,001	,000	,002	,000	,000	,000	-,558**
	Sig. (2-tailed)	,000	,001	,765	,000	,072	,377	,377	,377	,784	,943	,592	1,000	1,000	1,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
Win	Pearson Corr.	-,008*	,018**	,000	-,032**	-,001	-,001	-,001	-,001	,000	,000	,000	,000	,000	,000	,361**
	Sig. (2-tailed)	,016	,000	,966	,000	,641	,697	,697	,697	,897	,938	,885	1,000	1,000	1,000	0,000
	N	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920	97920
EPC	Pearson Corr.	,013**	,032**	,000	,030**	-,046**	,001	,001	,001	,001	,001	,001	,000	,000	,000	-,236**
	Sig. (2-tailed)	,000	,000	,947	,000	,000	,736	,736	,736	,776	,689	,854	1,000	1,000	1,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
In1	Pearson Corr.	-,007*	-,033**	,000	-,006	,043**	,000	,000	,000	-,001	-,001	,000	0,000	0,000	0,000	,047**
	Sig. (2-tailed)	,015	,000	,905	,057	,000	,963	,963	,963	,815	,779	,872	1,000	1,000	1,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
In2	Pearson Corr.	-,007*	-,033**	-,001	-,008**	,042**	,000	,000	,000	,000	,000	-,001	0,000	0,000	0,000	-,249**
	Sig. (2-tailed)	,015	,000	,816	,008	,000	,949	,949	,949	,939	,888	,741	1,000	1,000	1,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
In3	Pearson Corr.	-,011**	-,024**	,000	,038**	,058**	,001	,001	,001	-,001	,000	,001	0,000	0,000	0,000	,373**
	Sig. (2-tailed)	,000	,000	,886	,000	,000	,740	,740	,740	,698	,955	,799	1,000	1,000	1,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
In4	Pearson Corr.	-,008**	,005	-,001	-,004	,045**	,000	,000	,000	,000	-,001	-,001	0,000	0,000	0,000	,322**
	Sig. (2-tailed)	,009	,118	,835	,198	,000	,977	,977	,977	,887	,865	,799	1,000	1,000	1,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
In5	Pearson Corr.	-,009**	,004	,000	-,001	,052**	,000	,000	,000	-,001	-,001	,000	0,000	0,000	0,000	-,250**
	Sig. (2-tailed)	,003	,165	,940	,793	,000	,996	,996	,996	,704	,701	,965	1,000	1,000	1,000	0,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
PV	Pearson Corr.	,009**	,015**	,001	-,006	-,055**	,000	,000	,000	,000	,000	,001	0,000	0,000	0,000	,044**
	Sig. (2-tailed)	,002	,000	,745	,062	,000	,943	,943	,943	,923	,952	,749	1,000	1,000	1,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Pro	Pearson Corr.	,015**	,140**	,113**	,088**	,000	-,003	-,006	-,005	-,005	-,007*	-,009**	,120**	,195**	,013**	-,189**
	Sig. (2-tailed)	,000	0,000	,000	,000	,993	,412	,096	,119	,170	,027	,006	,000	0,000	,000	0,000
	N	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504
Tem	Pearson Corr.	,120**	,121**	,422**	,668**	,219**	,004	,002	,007*	,008**	-,002	-,003	,175**	,252**	,069**	,050**
	Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	,256	,613	,016	,008	,482	,372	0,000	0,000	,000	,000
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
Sun	Pearson Corr.	,012**	,270**	,172**	,133**	,021**	-,005	-,027**	-,022**	-,021**	-,038**	-,039**	,346**	,339**	-,007*	,006
	Sig. (2-tailed)	,000	0,000	0,000	0,000	,000	,082	,000	,000	,000	,000	,000	0,000	0,000	,019	,052
	N	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216	105216
		Va1	Ed1	Se1	Se2	Se3	Day1	Day2	Day3	Day4	Day5	Day6	Dp1	Dp2	Dp3	Apup

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

A	B
C	D

Part D

1	,323**	,435**	,221**	,036**	-,486**	-,264**	,404**	,338**	,311**	,448**	,227**	,001	,000	Fac	Pearson Corr.
	0,000	0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,648	,991		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,323**	1	,507**	-,427**	,435**	-,192**	-,237**	-,103**	-,148**	1,000**	-,025**	,045**	-,018**	-,002	Flo	Pearson Corr.
0,000		0,000	0,000	0,000	0,000	0,000	,000	0,000	0,000	,000	,000	,000	,631		Sig. (2-tailed)
97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	97176	79488	97176	97176		N
,435**	,507**	1	-,151**	-,348**	,092**	-,357**	,294**	-,223**	,442**	,632**	,369**	-,061**	-,008*	Roo	Pearson Corr.
0,000	0,000		0,000	0,000	,000	0,000	0,000	0,000	0,000	0,000	0,000	,000	,016		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,221**	-,427**	-,151**	1	-,175**	-,219**	-,270**	-,044**	,929**	-,408**	-,048**	-,089**	-,007*	-,001	Win	Pearson Corr.
0,000	0,000	0,000		0,000	0,000	0,000	,000	0,000	0,000	,000	,000	,022	,689		Sig. (2-tailed)
97920	97176	97920	97920	97920	97920	97920	97920	97920	97920	97920	80232	97920	97920		N
,036**	,435**	-,348**	-,175**	1	-,420**	-,310**	-,843**	-,344**	-,255**	,098**	,324**	,027**	,007*	EPC	Pearson Corr.
,000	0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	,000	0,000	,000	,032		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
-,486**	-,192**	,092**	-,219**	-,420**	1	,070**	,295**	,203**	,320**	-,472**	-,078**	-,010**	-,004	In1	Pearson Corr.
0,000	0,000	,000	0,000	0,000		,000	0,000	0,000	0,000	0,000	,000	,002	,164		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
-,264**	-,237**	-,357**	-,270**	-,310**	,070**	1	,264**	,159**	,291**	-,626**	-,303**	,003	-,003	In2	Pearson Corr.
0,000	0,000	0,000	0,000	0,000	,000		0,000	0,000	0,000	0,000	0,000	,330	,315		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,404**	-,103**	,294**	-,044**	-,843**	,295**	,264**	1	,344**	,434**	-,100**	-,324**	,004	-,004	In3	Pearson Corr.
0,000	,000	0,000	,000	0,000	0,000	0,000		0,000	0,000	,000	0,000	,153	,244		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,338**	-,148**	-,223**	,929**	-,344**	,203**	,159**	,344**	1	,366**	-,579**	-,270**	,000	-,004	In4	Pearson Corr.
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	0,000	,899	,253		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,311**	1,000**	,442**	-,408**	-,255**	,320**	,291**	,434**	,366**	1	-,542**	-,316**	-,017**	-,006	In5	Pearson Corr.
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	,000	,069		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,448**	-,025**	,632**	-,048**	,098**	-,472**	-,626**	-,100**	-,579**	-,542**	1	,418**	-,013**	,003	PV	Pearson Corr.
0,000	,000	0,000	,000	,000	0,000	0,000	,000	0,000	0,000		0,000	,000	,332		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,227**	,045**	,369**	-,089**	,324**	-,078**	-,303**	-,324**	-,270**	-,316**	,418**	1	,209**	,237**	Pro	Pearson Corr.
0,000	,000	0,000	,000	0,000	,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000		Sig. (2-tailed)
80232	79488	80232	80232	87504	87504	87504	87504	87504	87504	87504	87504	87504	87504		N
,001	-,018**	-,061**	-,007*	,027**	-,010**	,003	,004	,000	-,017**	-,013**	,209**	1	,370**	Tem	Pearson Corr.
,648	,000	,000	,022	,000	,002	,330	,153	,899	,000	,000	0,000		0,000		Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
,000	-,002	-,008*	-,001	,007*	-,004	-,003	-,004	-,004	-,006	,003	,237**	,370**	1	Sun	Pearson Corr.
,991	,631	,016	,689	,032	,164	,315	,244	,253	,069	,332	0,000	0,000			Sig. (2-tailed)
97920	97176	97920	97920	105216	105216	105216	105216	105216	105216	105216	87504	105216	105216		N
Fac	Flo	Roo	Win	EPC	In1	In2	In3	In4	In5	PV	Pro	Tem	Sun		

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

0,000 - 0,599	Little correlation
0,600 - 0,799	Strong correlation
0,800 - 1,000	Very strong correlation

APPENDIX E. CALCULATION CORRELATION COEFFICIENT (R) AND COEFFICIENT OF DETERMINATION (R^2)

The equation for calculating the correlation coefficient (Statistics How To, 2018) =

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

$$r^2 = \left(\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}\right)^2$$

Without log transformation:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \ldots + \beta_n X_n$

$\sum X$	=	616995
$\sum Y$	=	617034
$\sum XY$	=	6075760
$\sum X^2$	=	6075501
$\sum Y^2$	=	7345237
n	=	105216

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

$$r = \frac{(105216 * 6075760) - (616995 * 617034)}{\sqrt{[105216 * 6075501 - (616995)^2][105216 * 7345237 - (617034)^2]}}$$

$$r = 0.812049$$

$$r^2 = 0.812049^2 = 0.659423$$

With log transformation:

$\ln(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \ldots + \beta_n X_n$

$\sum X$	=	126296
$\sum Y$	=	126282
$\sum XY$	=	239386
$\sum X^2$	=	239401
$\sum Y^2$	=	413805
n	=	105216

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

$$r = \frac{(105216 * 239386) - (126296 * 126282)}{\sqrt{[105216 * 239401 - (126296)^2][105216 * 413805 - (126282)^2]}}$$

$r = 0.57864$

$r^2 = 0.57864^2 = 0.334824$

With log transformation and exponential:

$\exp(\ln(Y)) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \ldots + \beta_nX_n$

∑ X	=	126296
∑ Y	=	617034
∑ XY	=	1155767
∑ X²	=	239401
∑ Y²	=	7345237
n	=	105216

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

$$r = \frac{(105216 * 1155767) - (126296 * 617034)}{\sqrt{[105216 * 239401 - (126296)^2][105216 * 7345237 - (617034)^2]}}$$

$r = 0.725691$

$r^2 = 0.725691^2 = 0.526628$

APPENDIX F. MODEL ESTIMATION Y (PANEL DATA)

```
|-> REGRESS ; Lhs = CON ; Rhs = x,one ; Panel ; Fixed Effects ; Parameters ;
Output = 2 $
+-------------------------------------------------------------------+
| Variable = ____________ Variable Groups     Max     Min   Average |
| TI         Group sizes  ID            10  17544     720   10521.6 |
+-------------------------------------------------------------------+

-----------------------------------------------------------------------------
Ordinary     least squares regression ...........
LHS=CON      Mean                  =        5.86445
             Standard deviation    =        5.95144
----------   No. of observations   =         105216  DegFreedom   Mean square
Regression   Sum of Squares        =    .245746E+07          24  102394.00161
Residual     Sum of Squares        =    .126922E+07      105191      12.06585
Total        Sum of Squares        =    .372667E+07      105215      35.41961
----------   Standard error of e   =        3.47359  Root MSE         3.47318
Fit          R-squared             =         .65942  R-bar squared     .65935
Model test   F[ 24,105191]         =     8486.26825  Prob F > F*       .00000
B-P test     Chi squared [  1]     =        1.29129  Prob C2 > C2* =   .25581
[High values of  LM favor FEM/REM over base model]
Baltagi-Li form of LM Statistic    =         .09854  [= BP if balanced panel]
Moulton/Randolph form:SLM N[0,1]   =        1.43369
Model was estimated on Apr 12, 2018 at 00:00:59 PM
--------------------------------------------------
Panel Data Analysis of CON                 [ONE way]
               Unconditional ANOVA (No regressors)
Source         Variation   Deg. Free.   Mean Square
Between     474111.34432          9.   52679.03826
Residual   3252563.04828     105206.      30.91614
Total      3726674.39259     105215.      35.41961
--------+--------------------------------------------------------------------
        |                 Standard            Prob.      95% Confidence
     CON|  Coefficient      Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
     VA1|   -.52396***      .01347   -38.91  .0000      -.55035   -.49757
     ED1|   3.98319***      .01795   221.94  .0000      3.94801   4.01836
     SE1|   -.54757***      .01937   -28.27  .0000      -.58554   -.50960
     SE2|   -.16235***      .02495    -6.51  .0000      -.21124   -.11345
     SE3|    .07791***      .02011     3.87  .0001       .03849    .11733
    DAY1|    .97643***      .02640    36.99  .0000       .92468   1.02817
    DAY2|    .94706***      .02641    35.86  .0000       .89530    .99882
    DAY3|    .82732***      .02631    31.45  .0000       .77576    .87888
    DAY4|    .80121***      .02632    30.44  .0000       .74962    .85280
    DAY5|    .30305***      .02632    11.52  .0000       .25147    .35463
    DAY6|  -1.86411***      .02674   -69.72  .0000     -1.91651  -1.81171
     DP1|   1.31645***      .02072    63.52  .0000      1.27583   1.35706
     DP2|   1.65566***      .02036    81.31  .0000      1.61574   1.69557
     DP3|  -1.22296***      .02031   -60.23  .0000     -1.26275  -1.18316
    APUP|    .18704***      .01502    12.45  .0000       .15760    .21649
     EPC|  -1.28444***      .13177    -9.75  .0000     -1.54269  -1.02618
     IN1|  -2.20615***      .06272   -35.18  .0000     -2.32907  -2.08323
     IN2|   -.83185***      .08475    -9.81  .0000      -.99796   -.66573
     IN3|  -2.11263***      .09585   -22.04  .0000     -2.30050  -1.92477
     IN4|   3.40481***      .06353    53.60  .0000      3.28031   3.52932
     IN5|   1.62927***      .07967    20.45  .0000      1.47311   1.78543
      PV|    .00463***      .00038    12.26  .0000       .00389    .00537
     TEM|   -.10781***      .00250   -43.19  .0000      -.11270   -.10291
     SUN|   -.04034***      .00376   -10.72  .0000      -.04771   -.03296
Constant|   9.21001***      .22980    40.08  .0000      8.75960   9.66042
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------
```

```
-----------------------------------------------------------------------------
LSDV         least squares with fixed effects ....
LHS=CON      Mean                 =        5.86445
             Standard deviation   =        5.95144
----------   No. of observations  =         105216  DegFreedom   Mean square
Regression   Sum of Squares       =    .245749E+07          33   74469.25429
Residual     Sum of Squares       =    .126919E+07      105182      12.06660
Total        Sum of Squares       =    .372667E+07      105215      35.41961
----------   Standard error of e  =        3.47370  Root MSE         3.47314
Fit          R-squared            =         .65943  R-bar squared     .65932
Model test   F[ 33,105182]        =     6171.51984  Prob F > F*       .00000
Estd. Autocorrelation of e(i,t)   =        .784435
--------------------------------------------------
Panel:Groups Empty        0,     Valid data     10
             Smallest 720,     Largest       17544
             Average group size in panel  10521.60
Variances    Effects a(i)         Residuals e(i,t)
                 282.154550              12.066599
Rho squared: Residual variation due to ai  .958988
Within groups variation in CON        3252563.0483
R squared based on within group variation  .609788
Between group variation in CON         474111.3443
**************************************************
These  8 variables have no within group variation.
APUP     EPC      IN1      IN2      IN3      more
They are  not included in the fixed effects model.
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
     CON|  Coefficient     Error      z     |z|>Z*         Interval
--------+--------------------------------------------------------------------
     VA1|   -.52402***     .01347   -38.91  .0000     -.55041   -.49762
     ED1|   3.98306***     .01795   221.93  .0000     3.94788   4.01824
     SE1|   -.54762***     .01937   -28.27  .0000     -.58559   -.50965
     SE2|   -.16223***     .02495    -6.50  .0000     -.21113   -.11333
     SE3|    .07790***     .02011     3.87  .0001      .03848    .11732
    DAY1|    .97644***     .02640    36.98  .0000      .92470   1.02819
    DAY2|    .94708***     .02641    35.86  .0000      .89532    .99884
    DAY3|    .82733***     .02631    31.45  .0000      .77576    .87889
    DAY4|    .80123***     .02632    30.44  .0000      .74964    .85282
    DAY5|    .30307***     .02632    11.52  .0000      .25149    .35465
    DAY6|  -1.86414***     .02674   -69.72  .0000    -1.91654  -1.81174
     DP1|   1.31650***     .02072    63.52  .0000     1.27588   1.35712
     DP2|   1.65569***     .02036    81.30  .0000     1.61578   1.69560
     DP3|  -1.22300***     .02031   -60.23  .0000    -1.26280  -1.18320
    APUP|        0.0    .....(Fixed Parameter).....
     EPC|        0.0    .....(Fixed Parameter).....
     IN1|        0.0    .....(Fixed Parameter).....
     IN2|        0.0    .....(Fixed Parameter).....
     IN3|        0.0    .....(Fixed Parameter).....
     IN4|        0.0    .....(Fixed Parameter).....
     IN5|        0.0    .....(Fixed Parameter).....
      PV|        0.0    .....(Fixed Parameter).....
     TEM|   -.10781***     .00250   -43.19  .0000     -.11270   -.10292
     SUN|   -.04033***     .00376   -10.71  .0000     -.04771   -.03296
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
Fixed parameter ... is constrained to equal the value or
had a nonpositive st.error because of an earlier problem.
-----------------------------------------------------------------------------

        Estimated Fixed Effects
        Group        Coefficient         Standard Error       t-ratio
            1            7.52547                 .03711     202.76519
```

2	8.46583	.02623	322.80569
3	7.57764	.02623	288.93889
4	8.49956	.02623	324.09209
5	10.45921	.03711	281.81138
6	7.35159	.12946	56.78783
7	13.11908	.02623	500.23618
8	10.60487	.03711	285.73588
9	8.84719	.12735	69.47032
10	11.50525	.04067	282.90861

Test Statistics for the Fixed Effects Regression Model

	Model	Log-Likelihood	Sum of Squares	R-squared
(1)	Constant term only	-336961.24850	3726674.39259	.00000
(2)	Group effects only	-329802.72346	3252563.04828	.12722
(3)	X - variables only	-280296.38202	1269218.35390	.65942
(4)	X and group effects	-280295.16535	1269189.00090	.65943

Hypothesis Tests

	Likelihood Ratio Test			F Tests			
	Chi-squared	d.f.	Prob	F	num	denom	P value
(2) vs (1)	14317.05	9	.0000	1703.93	9	105206	.00000
(3) vs (1)	113329.73	24	.0000	8486.27	24	105191	.00000
(4) vs (1)	113332.17	33	.0000	6171.52	33	105182	.00000
(4) vs (2)	99015.12	24	.0000	6848.71	24	105182	.00000
(4) vs (3)	2.43	9	.9826	.27	9	105182	.98264

APPENDIX G. MODEL ESTIMATION LN(Y) (PANEL DATA)

```
|-> REGRESS ; Lhs = CON3 ; Rhs = x,one ; Panel ; Fixed Effects ; Parameters ;
Output = 2 $
+-------------------------------------------------------------------+
| Variable = ____________ Variable Groups    Max    Min   Average |
| TI         Group sizes  ID            10  17544    720   10521.6 |
+-------------------------------------------------------------------+

-----------------------------------------------------------------------------
Ordinary     least squares regression ...........
LHS=CON3     Mean                 =       1.20022
             Standard deviation   =       1.57874
----------   No. of observations  =        105216  DegFreedom   Mean square
Regression   Sum of Squares       =       87803.8          24   3658.49089
Residual     Sum of Squares       =       174435.      105191      1.65827
Total        Sum of Squares       =       262238.      105215      2.49241
----------   Standard error of e  =       1.28774  Root MSE        1.28758
Fit          R-squared            =        .33482  R-bar squared     .33467
Model test   F[ 24,105191]        =    2206.21427  Prob F > F*       .00000
B-P test     Chi squared [   1]   =     232.31391  Prob C2 > C2* =   .00000
[High values of  LM favor FEM/REM over base model]
Baltagi-Li form of LM Statistic   =      17.72747  [= BP if balanced panel]
Moulton/Randolph form:SLM N[0,1]  =      52.89784
Model was estimated on Apr 12, 2018 at 11:57:20 AM
--------------------------------------------------
Panel Data Analysis of CON3               [ONE way]
              Unconditional ANOVA (No regressors)
Source        Variation   Deg. Free.   Mean Square
Between      28680.15666          9.    3186.68407
Residual    233558.32101     105206.       2.22001
Total       262238.47767     105215.       2.49241
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
    CON3|  Coefficient      Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
     VA1|   -.14503***      .00499   -29.05  .0000     -.15481   -.13524
     ED1|    .58903***      .00665    88.53  .0000      .57599    .60207
     SE1|   -.11446***      .00718   -15.94  .0000     -.12854   -.10038
     SE2|   -.04104***      .00925    -4.44  .0000     -.05916   -.02291
     SE3|    .03024***      .00746     4.06  .0001      .01562    .04485
    DAY1|    .23433***      .00979    23.94  .0000      .21514    .25351
    DAY2|    .26437***      .00979    27.00  .0000      .24518    .28355
    DAY3|    .23540***      .00975    24.14  .0000      .21628    .25451
    DAY4|    .23061***      .00976    23.63  .0000      .21148    .24973
    DAY5|    .15734***      .00976    16.13  .0000      .13822    .17646
    DAY6|   -.52672***      .00991   -53.14  .0000     -.54615   -.50730
     DP1|    .20188***      .00768    26.28  .0000      .18683    .21694
     DP2|    .11790***      .00755    15.62  .0000      .10311    .13270
     DP3|   -.10966***      .00753   -14.57  .0000     -.12441   -.09490
    APUP|    .11857***      .00557    21.29  .0000      .10765    .12948
     EPC|  -2.08833***      .04885   -42.75  .0000    -2.18408  -1.99259
     IN1|  -1.19369***      .02325   -51.34  .0000    -1.23926  -1.14812
     IN2|   -.63374***      .03142   -20.17  .0000     -.69532   -.57215
     IN3|   -.77203***      .03553   -21.73  .0000     -.84167   -.70238
     IN4|    .00191         .02355      .08  .9353     -.04425    .04807
     IN5|    .61090***      .02954    20.68  .0000      .55301    .66879
      PV|   -.00256***      .00014   -18.28  .0000     -.00284   -.00229
     TEM|   -.02725***      .00093   -29.44  .0000     -.02906   -.02543
     SUN|   -.03248***      .00140   -23.28  .0000     -.03522   -.02975
Constant|   3.38480***      .08519    39.73  .0000     3.21783   3.55178
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
```

```
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------
LSDV         least squares with fixed effects ....
LHS=CON3     Mean                 =        1.20022
             Standard deviation   =        1.57874
----------   No. of observations  =         105216  DegFreedom   Mean square
Regression   Sum of Squares       =        87893.1          33    2663.42727
Residual     Sum of Squares       =        174345.      105182       1.65756
Total        Sum of Squares       =        262238.      105215       2.49241
----------   Standard error of e  =        1.28746  Root MSE         1.28725
Fit          R-squared            =         .33516  R-bar squared     .33496
Model test   F[ 33,105182]        =     1606.83702  Prob F > F*       .00000
Estd. Autocorrelation of e(i,t)   =        .761450
--------------------------------------------------------------------------------
Panel:Groups Empty        0,     Valid data        10
             Smallest 720,       Largest        17544
             Average group size in panel   10521.60
Variances    Effects a(i)          Residuals e(i,t)
                 22.519390                 1.657559
Rho squared: Residual variation due to ai   .931441
Within groups variation in CON3         233558.3210
R squared based on within group variation  .253525
Between group variation in CON3          28680.1567
**************************************************
These  8 variables have no within group variation.
APUP     EPC       IN1       IN2       IN3       more
They are  not included in the fixed effects model.
--------+-----------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
    CON3|  Coefficient     Error       z    |z|>Z*         Interval
--------+-----------------------------------------------------------------------
     VA1|   -.14512***      .00499   -29.08  .0000     -.15491   -.13534
     ED1|    .58880***      .00665    88.52  .0000      .57576    .60184
     SE1|   -.11454***      .00718   -15.95  .0000     -.12861   -.10046
     SE2|   -.04083***      .00925    -4.42  .0000     -.05896   -.02271
     SE3|    .03021***      .00745     4.05  .0001      .01560    .04482
    DAY1|    .23436***      .00979    23.95  .0000      .21518    .25353
    DAY2|    .26439***      .00979    27.01  .0000      .24521    .28358
    DAY3|    .23540***      .00975    24.14  .0000      .21629    .25452
    DAY4|    .23063***      .00976    23.64  .0000      .21151    .24975
    DAY5|    .15737***      .00975    16.13  .0000      .13825    .17649
    DAY6|   -.52677***      .00991   -53.16  .0000     -.54620   -.50735
     DP1|    .20197***      .00768    26.30  .0000      .18692    .21703
     DP2|    .11796***      .00755    15.63  .0000      .10317    .13276
     DP3|   -.10973***      .00753   -14.58  .0000     -.12448   -.09498
    APUP|      0.0     .....(Fixed Parameter).....
     EPC|      0.0     .....(Fixed Parameter).....
     IN1|      0.0     .....(Fixed Parameter).....
     IN2|      0.0     .....(Fixed Parameter).....
     IN3|      0.0     .....(Fixed Parameter).....
     IN4|      0.0     .....(Fixed Parameter).....
     IN5|      0.0     .....(Fixed Parameter).....
      PV|      0.0     .....(Fixed Parameter).....
     TEM|   -.02725***      .00093   -29.46  .0000     -.02907   -.02544
     SUN|   -.03248***      .00140   -23.28  .0000     -.03522   -.02975
--------+-----------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
Fixed parameter ... is constrained to equal the value or
had a nonpositive st.error because of an earlier problem.
--------------------------------------------------------------------------------

        Estimated Fixed Effects
        Group       Coefficient       Standard Error       t-ratio
```

1	.71630	.01376	52.07273
2	1.78061	.00972	183.18898
3	1.65088	.00972	169.84197
4	1.85345	.00972	190.68225
5	2.08677	.01376	151.70204
6	1.24204	.04798	25.88615
7	2.68696	.00972	276.43346
8	2.31447	.01376	168.25562
9	1.93590	.04720	41.01435
10	1.66974	.01507	110.77908

Test Statistics for the Fixed Effects Regression Model

	Model	Log-Likelihood	Sum of Squares	R-squared
(1)	Constant term only	-197338.71052	262238.47767	.00000
(2)	Group effects only	-191245.52070	233558.32101	.10937
(3)	X - variables only	-175890.22523	174434.69624	.33482
(4)	X and group effects	-175863.28069	174345.37791	.33516

Hypothesis Tests

	Likelihood Ratio Test			F Tests			
	Chi-squared	d.f.	Prob	F	num	denom	P value
(2) vs (1)	12186.38	9	.0000	1435.44	9	105206	.00000
(3) vs (1)	42896.97	24	.0000	2206.21	24	105191	.00000
(4) vs (1)	42950.86	33	.0000	1606.84	33	105182	.00000
(4) vs (2)	30764.48	24	.0000	1488.46	24	105182	.00000
(4) vs (3)	53.89	9	.0000	5.99	9	105182	.00000

APPENDIX H. FRACTIONAL FACTORIAL DESIGN IN WORDS (2)

Profile	Class size	Heating system	Ventilation system	Lighting	PV panels	Sun blinds	Heating system	Ventilation system	Lighting	PV panels	Sun blinds
1	Large (33 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
2	Large (33 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
3	Large (33 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually
4	Large (33 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
5	Large (33 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually
6	Large (33 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually
7	Small (19 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
8	Small (19 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
9	Small (19 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually

10	Small (19 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
11	Small (19 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually
12	Small (19 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually
13	Large (33 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually
14	Large (33 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually
15	Large (33 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
16	Large (33 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
17	Large (33 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
18	Large (33 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually
19	Small (19 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% less greenhouse gas emissions and at the end of the lesson the	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually

					be lower (17 °C)		classroom warms up				
20	Small (19 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually
21	Small (19 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
22	Small (19 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
23	Small (19 pupils)	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually	20% more greenhouse gas emissions and the classroom is quickly warmed up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Noise in the middle of the lessons due to lowing the sun blinds automatically
24	Small (19 pupils)	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Fresh air and background noise by ventilation system	After the lesson, lights need to be switched off manually	10% less greenhouse gas emissions and temperature can sometimes be lower (17 °C)	Sun blinds need to be done manually	20% less greenhouse gas emissions and at the end of the lesson the classroom warms up	Quiet classroom with polluted air	Lighting switches off if no movements are detected	10% more greenhouse gas emissions and healthy room temperature (21 °C)	Sun blinds need to be done manually

APPENDIX I. RHO SQUARED (ρ^2)

PUPIL DATASET

MNL LOGIT MODEL:

LL(0) = LN(1/3) * 3516 = -3862.72
LL(B) = -3304.04

$\rho^2 = 1 – (LL(B)/LL(0)) = 1 – (-3304.04 / -3862.72) = 1 – 0.8554 = 0.1446$

RP LOGIT MODEL:

LL(0) = LN(1/3) * 3516 = -3862.72
LL(B) = -3188.43

$\rho^2 = 1 – (LL(B)/LL(0)) = 1 – (-3188.43 / -3862.72) = 1 – 0.8254 = 0.1746$

TEACHER DATASET

MNL LOGIT MODEL:

LL(0) = LN(1/3) * 996 = -1094.22
LL(B) = -992.95

$\rho^2 = 1 – (LL(B)/LL(0)) = 1 – (-992.95 / -1094.22) = 1 – 0.9075 = 0.0925$

RP LOGIT MODEL:

LL(0) = LN(1/3) * 996 = -1094.22
LL(B) = -937.43

$\rho^2 = 1 – (LL(B)/LL(0)) = 1 – (-937.43 / -1094.22) = 1 – 0.8567 = 0.1433$

PUPIL / TEACHER COMBINED DATASET

MNL LOGIT MODEL:

LL(0) = LN(1/3) * 4512 = -4956.94
LL(B) = -4340.62

$\rho^2 = 1 – (LL(B)/LL(0)) = 1 – (-4340.62 / -4956.94) = 1 – 0.8757 = 0.1243$

RP LOGIT MODEL:

LL(0) = LN(1/3) * 4512 = -4956.94
LL(B) = -4175.08

$\rho^2 = 1 – (LL(B)/LL(0)) = 1 – (-4175.08 / -4956.94) = 1 – 0.8423 = 0.1577$

APPENDIX J. MNL & MXL MODEL (PUPIL DATASET)

```
|-> RPLOGIT ; Lhs = CH ; Choices = r1,r2,none ; Rhs = con,si,he,ve,li,pv,bl ;
Pts=1000 ; Halton ; Fcn=si(n),he(n),ve(n),li(n),pv(n),bl(n) ;Pds=12 $
Normal exit:   5 iterations. Status=0, F=    3304.044

-----------------------------------------------------------------------------
Start values obtained using MNL model
Dependent variable              Choice
Log likelihood function    -3304.04362
Estimation based on N =   3516, K =   7
Inf.Cr.AIC  =   6622.1 AIC/N =    1.883
Model estimated: Apr 05, 2018, 14:46:52
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -3608.5235  .0844 .0827
Response data are given as ind. choices
Number of obs.=  3516, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
      CH|  Coefficient     Error         z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
      SI|    -.01273        .04606      -.28  .7823     -.10300    .07755
      HE|    -.02304        .02613      -.88  .3780     -.07426    .02818
      VE|    -.49826***     .02554    -19.51  .0000     -.54832   -.44820
      LI|     .16394***     .02777      5.90  .0000      .10950    .21837
      PV|     .19143***     .02605      7.35  .0000      .14037    .24249
      BL|     .31906***     .02680     11.91  .0000      .26654    .37159
     CON|     .89697***     .04618     19.42  .0000      .80646    .98748
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------

Normal exit:  17 iterations. Status=0, F=    3188.427

-----------------------------------------------------------------------------
Random Parameters Logit Model
Dependent variable                  CH
Log likelihood function    -3188.42712
Restricted log likelihood  -3862.72081
Chi squared [  13 d.f.]     1348.58736
Significance level              .00000
McFadden Pseudo R-squared     .1745644
Estimation based on N =   3516, K =  13
Inf.Cr.AIC  =   6402.9 AIC/N =    1.821
Model estimated: Apr 05, 2018, 15:01:37
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
No coefficients -3862.7208  .1746 .1730
Constants only  -3608.5235  .1164 .1148
At start values -3304.0436  .0350 .0332
Response data are given as ind. choices
Replications for simulated probs. =1000
Used Halton sequences in simulations.
RPL model with panel has      293 groups
Fixed number of obsrvs./group=      12
Number of obs.=  3516, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
      CH|  Coefficient     Error         z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
        |Random parameters in utility functions
      SI|    -.01413        .04848      -.29  .7708     -.10914    .08089
      HE|    -.02455        .03751      -.65  .5127     -.09807    .04896
      VE|    -.64233***     .04837    -13.28  .0000     -.73714   -.54752
      LI|     .22385***     .03921      5.71  .0000      .14699    .30070
```

```
      PV|     .21896***      .04307     5.08  .0000       .13455    .30337
      BL|     .33668***      .03902     8.63  .0000       .26019    .41316
        |Nonrandom parameters in utility functions
     CON|     .89308***      .04928    18.12  .0000       .79650    .98967
        |Distns. of RPs. Std.Devs or limits of triangular
    NsSI|     .00739         .10409      .07  .9434     -.19663    .21141
    NsHE|     .33592***      .05454     6.16  .0000       .22903    .44282
    NsVE|     .59628***      .04971    12.00  .0000       .49886    .69370
    NsLI|     .33527***      .05637     5.95  .0000       .22478    .44575
    NsPV|     .48522***      .04996     9.71  .0000       .38730    .58314
    NsBL|     .37512***      .05189     7.23  .0000       .27341    .47683
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------
```

APPENDIX K. MNL & MXL MODEL (TEACHER DATASET)

```
|-> RPLOGIT ; Lhs = CH ; Choices = r1,r2,none ; Rhs = con,si,he,ve,li,pv,bl ;
Pts=1000 ; Halton ; Fcn=si(n),he(n),ve(n),li(n),pv(n),bl(n) ;Pds=12 $
Normal exit:   5 iterations. Status=0, F=    992.9466

-----------------------------------------------------------------------------
Start values obtained using MNL model
Dependent variable                Choice
Log likelihood function      -992.94656
Estimation based on N =    996, K =   7
Inf.Cr.AIC  =   1999.9 AIC/N =    2.008
Model estimated: Apr 05, 2018, 15:10:41
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -1084.7426  .0846 .0786
Response data are given as ind. choices
Number of obs.=    996, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
      CH|  Coefficient     Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
      SI|    -.11234         .07156    -1.57  .1165     -.25260     .02792
      HE|    -.03946         .05022     -.79  .4319     -.13789     .05896
      VE|    -.54093***      .05311   -10.18  .0000     -.64502    -.43683
      LI|     .28838***      .05220     5.52  .0000      .18606     .39069
      PV|     .05245         .05298      .99  .3221     -.05138     .15629
      BL|     .30068***      .04980     6.04  .0000      .20308     .39829
     CON|     .13611*        .07242     1.88  .0602     -.00584     .27806
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------

Normal exit:  18 iterations. Status=0, F=    937.4300

-----------------------------------------------------------------------------
Random Parameters Logit Model
Dependent variable                    CH
Log likelihood function      -937.43000
Restricted log likelihood   -1094.21784
Chi squared [  13 d.f.]       313.57567
Significance level               .00000
McFadden Pseudo R-squared      .1432876
Estimation based on N =    996, K =  13
Inf.Cr.AIC  =   1900.9 AIC/N =    1.908
Model estimated: Apr 05, 2018, 15:15:28
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
No coefficients -1094.2178  .1433 .1377
Constants only  -1084.7426  .1358 .1301
At start values  -992.9466  .0559 .0497
Response data are given as ind. choices
Replications for simulated probs. =1000
Used Halton sequences in simulations.
RPL model with panel has       83 groups
Fixed number of obsrvs./group=       12
Number of obs.=    996, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
      CH|  Coefficient     Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
        |Random parameters in utility functions
      SI|    -.13487*        .07849    -1.72  .0857     -.28871     .01897
      HE|    -.05175         .09073     -.57  .5684     -.22959     .12608
      VE|    -.74691***      .10894    -6.86  .0000     -.96044    -.53339
      LI|     .37289***      .09433     3.95  .0001      .18801     .55777
```

```
     PV|    -.01879         .08660     -.22  .8282     -.18852    .15093
     BL|     .28438***      .09225     3.08  .0021      .10357    .46518
       |Nonrandom parameters in utility functions
    CON|     .01241         .08266      .15  .8807     -.14960    .17441
       |Distns. of RPs. Std.Devs or limits of triangular
   NsSI|     .00584         .10772      .05  .9568     -.20529    .21697
   NsHE|     .52548***      .10464     5.02  .0000      .32040    .73057
   NsVE|     .73364***      .10435     7.03  .0000      .52912    .93817
   NsLI|     .55570***      .11244     4.94  .0000      .33532    .77607
   NsPV|     .47618***      .10824     4.40  .0000      .26403    .68833
   NsBL|     .57482***      .10227     5.62  .0000      .37438    .77526
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------
```

APPENDIX L. MNL & MXL MODEL (PUPIL TEACHER COMBINED DATASET)

```
|-> RPLOGIT ; Lhs = CH ; Choices = r1,r2,none ; Rhs = con,si,he,ve,li,pv,bl ;
Pts=1000 ; Halton ; Fcn=si(n),he(n),ve(n),li(n),pv(n),bl(n) ;Pds=12 $
Normal exit:   5 iterations. Status=0, F=    4340.621

-----------------------------------------------------------------------------
Start values obtained using MNL model
Dependent variable                Choice
Log likelihood function      -4340.62103
Estimation based on N =    4512, K =   7
Inf.Cr.AIC  =    8695.2 AIC/N =    1.927
Model estimated: Apr 05, 2018, 15:42:13
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -4731.5258  .0826 .0813
Response data are given as ind. choices
Number of obs.=  4512, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
      CH|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
      SI|    -.04117         .03836    -1.07  .2831     -.11635    .03401
      HE|    -.02627         .02289    -1.15  .2511     -.07113    .01859
      VE|    -.50682***      .02296   -22.07  .0000     -.55183   -.46182
      LI|     .18984***      .02414     7.86  .0000      .14252    .23716
      PV|     .16735***      .02328     7.19  .0000      .12172    .21299
      BL|     .30794***      .02324    13.25  .0000      .26239    .35349
     CON|     .70361***      .03848    18.29  .0000      .62820    .77903
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------

Line search at iteration   18 does not improve fn. Exiting optimization.

-----------------------------------------------------------------------------
Random Parameters Logit Model
Dependent variable                    CH
Log likelihood function      -4175.07666
Restricted log likelihood    -4956.93865
Chi squared [  13 d.f.]       1563.72397
Significance level                .00000
McFadden Pseudo R-squared       .1577308
Estimation based on N =    4512, K =  13
Inf.Cr.AIC  =    8376.2 AIC/N =    1.856
Model estimated: Apr 05, 2018, 16:20:26
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
No coefficients -4956.9386  .1577 .1565
Constants only  -4731.5258  .1176 .1163
At start values -4340.6210  .0381 .0368
Response data are given as ind. choices
Replications for simulated probs. =1000
Used Halton sequences in simulations.
RPL model with panel has      376 groups
Fixed number of obsrvs./group=        12
Number of obs.=  4512, skipped    0 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
      CH|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
        |Random parameters in utility functions
      SI|    -.04635         .04069    -1.14  .2547     -.12609    .03340
      HE|    -.02670         .03461     -.77  .4405     -.09454    .04114
      VE|    -.66179***      .04430   -14.94  .0000     -.74861   -.57496
      LI|     .25395***      .03569     7.11  .0000      .18399    .32391
```

PV	.18112***	.03870	4.68	.0000	.10526	.25697
BL	.31249***	.03528	8.86	.0000	.24335	.38163
	Nonrandom parameters in utility functions					
CON	.68213***	.04145	16.46	.0000	.60090	.76336
	Distns. of RPs. Std.Devs or limits of triangular					
NsSI	.00789	.07206	.11	.9128	-.13334	.14913
NsHE	.37798***	.04698	8.04	.0000	.28589	.47006
NsVE	.62164***	.04508	13.79	.0000	.53330	.70999
NsLI	.36749***	.04833	7.60	.0000	.27276	.46221
NsPV	.48595***	.04482	10.84	.0000	.39810	.57379
NsBL	.40576***	.04480	9.06	.0000	.31795	.49356

Note: ***, **, * ==> Significance at 1%, 5%, 10% level.