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DIPLOMARBEIT

An inquiry into the specification potential of indoor environments' ecological valency

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KURZFASSUNG

Nutzer von Gebäuden haben üblicherweise die Möglichkeit die Innenraum-klimatischen Bedingungen mit der Hilfe von verschiedenen Elementen und Geräten zu steuern. Diese beinhalten beispielsweise Fenster, Leuchten, Heizkörper, und Verschattungssysteme. Abhängig von der Verfügbarkeit und Effektivität dieser Elemente wird die Qualität des Innenraumklimas beeinflusst. Aufgrund fehlender Zertifizierungsverfahren für das Innraumklima von Gebäuden im Sinne von Steuerbarkeit befasst sich diese Masterarbeit mit dem Evaluierungspotential von Ökologischer Valenz in Gebäuden. Dazu wird zunächst eine theoretische Grundlage (d.h. die Wiener Schule der Humanökologie) für diesen Zweck beschrieben. Zudem werden frühere diesbezügliche Bemühungen kurz umrissen. Anschließend wird ein Versuch für eine Ökologische Valenz Bewertungsmethode vorgestellt. Als Teil dieser Methode werden fünf Hauptkategorien von steuerbaren Geräten vorgeschlagen, welche in verschiedenen Räumen eines Gebäudes dokumentieren werden sollen. Diese beinhalten Fenster, Leuchten, Beschattung, Heiz-, und Kühlsysteme. Während sich der erste Teil dieser Methode auf die Verfügbarkeit dieser Steuerungsgeräte und Elemente bezieht, werden im zweiten Teil deren räumliche Verteilung, Wirksamkeit (objektiv und subjektiv), Qualität der Bedienbarkeit und ökologische Qualität bewertet. Die vorgestellte Bewertungsmethode wird für sechs verschiedene Räume eines Büros in einem Bildungsgebäude in Wien, Österreich getestet. Rund dreißig Teilnehmer führten die Bewertung anhand der vorgeschlagenen Methode einzeln durch. Dies dient dazu, die Verwendbarkeit der Methode selbst zu testen, aber auch um zu dokumentieren, inwieweit sich die Bewertungsergebnisse unterscheiden könnten, wenn der gleiche Raum von verschiedenen Teilnehmern bewertet wird. Während einige der Teilnehmer in diesem Büro arbeiten, waren andere vor der Auswertung damit nicht vertraut. Somit wird auch der Unterschied zwischen den Ergebnissen der Nutzer und der Besucher analysiert. Das Ergebnis dieses Experiments, aber auch das Feedback der Teilnehmer ist in dieser Masterarbeit enthalten.

Keywords

Human Ökologie, Ökologische Valenz, Qualität des Innenraumklimas, Benutzerkontrolle, Bewertungsmethode

ABSTRACT

Occupants of buildings usually have the opportunity to control the indoor environment with the help of different elements and devices. These include, for example, windows, luminaires, radiators, and shading systems. Depending on the availability and effectiveness of these devices, the quality of the indoor environment is affected. Due to the fact that there is a lack of certification procedures for this aspect of the indoor environment of buildings (i.e., controllability) this master thesis deals with the specification potential of the Ecological Valency in built spaces. Toward this end, first a potential theoretical foundation for this purpose is identified (in terms of the Vienna School of Human Ecology) and previous related efforts are briefly reviewed. Subsequently, a specific attempt for an Ecological Valency evaluation method is presented. As part of this approach, five main categories of control equipment are suggested to be documented in various rooms of a building. They include windows, shading, lights, heating and cooling systems. Whereas, the first component of this method deals with the availability of these control devices and elements, the second part looks at their spatial distribution, effectiveness (both objective and subjective), interface quality, and ecological quality. The presented evaluation method is tested for six different rooms of an office area in an educational building in Vienna, Austria. About thirty participants conducted the evaluation of this area based on the proposed method individually. This is done to test the usability of the method itself but also to document the degree to which the different evaluation results could diverge when the same room is evaluated by different participants. While some of the participants work in this office area, others were not familiar with it before conducting the evaluation. Hence, aside from the overall consistency of the results, the difference between the results from the occupants and the visitors is analyzed as well. The Outcome of this experiment but also the feedback from the participants are included in this master thesis.

Keywords

Human Ecology, Ecological Valency, Indoor environmental quality, User Control, Evaluation method

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CONTENTS

1 INTRODUCTION

1.1 Overview

Offering possibilities to control the indoor environmental conditions is an essential quality aspect of a building. Usually, interior spaces incorporate quite a few different control devices and elements. Examples for this equipment are windows, luminaires, radiators, fans, or shading systems like blinds.

A common function of this equipment is to influence indoor environmental conditions such as hygro-thermal and visual aspects or the air quality of the space. As an example, windows, shading systems and also luminaires are elements that can affect the visual environment. Furthermore, an example for an element influencing the air quality is a window. The hygro-thermal environment can be affected by windows, heating systems, humidifiers, etc.

Occupants can definitively benefit from effective means of indoor environment control. Nevertheless, not every space offers the same number and types of control equipment. Moreover, only the availability of a device does not automatically mean that it can satisfy occupants' needs. There are many other aspects that decide how a certain device performs. (Mahdavi 2018, Mahdavi and Berger 2019).

Therefore, the availability of the control devices as well as their quality in form of usability, effectiveness and human interfaces are part of the performance of the indoor environment. To reflect upon this circumstance, the reference in Human Ecology to the concept of “ecological valency” can be highly beneficial (Knötig 1992a, Knötig 1992b, Mahdavi 2016). This is also similar to the concept of “affordance” (Gibson 1977). Thus, the concept of ecological valency can be useful when buildings' responsiveness for occupants’ needs are to be described.

In this context, one could ask whether it is possible to evaluate the ecological valency of a building via an objective assessment. Within this master thesis this question is examined. The thesis is relevant to the building design and evaluation process in that it explores an ecological valency evaluation method. Toward this end, some background information about human ecology and previous effort pertaining to this topic are considered.

1.2 Motivation

Currently, different certification procedures for buildings are available. Usually, these procedures deal with issues such as the energy efficiency of buildings. In Austria, for example, an energy certificate has to be issued for every residential unit and building traded on the real estate market and also for those that are newly constructed or retrofitted (EAVG 2012).

However, it is noticeable that there is a lack of certification procedures for the indoor environment of buildings for example regarding their controllability. For this reason, this master thesis deals with exactly this issue by presenting a specific attempt for an ecological valency evaluation method.

1.3 Approach

The following chapters describe the path towards the deveolpment of an attempt for an ecological valency evaluation method. First of all, a theoretical foundation for this purpose is presented. Information is provided about the work of the Vienna School of Human Ecology. Imoprtant concepts pertaining this topic are explained as well.

Furthermore, this master thesis incloudes an overview about previous efforts regarding the certification potential of ecologcal valency. First of all, two publications are referred to. They include preliminary reflections on the topic. Moreover, they inform about the limits and challenges of objective ecological valency assessment efforts. The potential of such a method is discussed as well. In a next step, pervious assessment efforts are presented, that involve project work by graduate students.

The main part of this master thesis is dedicated to the desiging and implementation a procedure for an ecological valency evalutaion method. First, a general structure for such a kind of method is presented. Subsequently, this structure is tested in an experiment. The thesis presents and discusses the key results of this case study.

2 BACKGROUND

2.1 Overview

Regarding the concepts of human ecology there are many approaches and traditions. One of the noteworthy schools in human ecology is the so-called “Vienna School”. The founders of the “Vienna School of Human Ecology” were looking for an appropriate definition for the term “Human Ecology”. They specifyed human ecology as the ecology of the species Homo sapiens (Knötig 1991, Knötig 1992a, Knötig 1992b).

This definition composes out of the terms “ecology” and “Homo sapiens”. Both were defined before amoung others by Häckel and Linnaeus. Häckel (1868, p.286) specified ecology as the following:

„Unter Oecologie verstehen wir die gesammte Wissenschaft von den Beziehungen des Organismus zur umgebenden Aussenwelt.“

engl.: “By ecology we understand the total scientific discipline dealing with the relationships of the organism to the surrounding outside world” (Knötig 1992b, p.4).

The definition for the term Homo sapiens by Linnaeus (1758, p.20) is provided hereafter:

“nosce te ipsum”

engl:” know thyself” (Knötig 1992b, p.4).

In Häckels (1868) definition two scenarios were considered. On the one hand it includes the relationship between one organism and the surroundings and on the other hand also a relationship between a number of organisms and the surrounding outside world. Later on, three terms were developed to make a discrimination between the scenario where the living beings are part of the same species and the case where they belong to different species. (Knötig 1992b) This new structure was defined by Schwerdtfeger (1963) and is shown in Table 1.

Table 1 Autecology, Demecology and Synecology (Schwerdtfeger 1963)

Autecology	deals with the interrelationships between	one living being	the surroundings (the surrounding outside world)
Demecology		a number of living beings all belonging to one species (“homotypic collective”	
Synecology		a number of living beings belonging to different species (“heterotypic collective”)	

In case of Human Ecology, due to the fact that it is defined as the species of Homo sapiens, only the Demecology and the Synecology are considered. Subsequently, a further classification has been made. (Knötig 1992a, Knötig 1992b) This is shown in Table 2.

Table 2 Characteristics of Individual Ecology and Social Ecology (Knötig 1992)

	“S2”	“S3”
Human Autecology “Individual Ecology”	One human being (“individual”)	The surrounding (the surrounding outside world)
Human Demecology “Social Ecology”	A number of human beings (“ensemble”)	The surrounding (the surrounding outside world)

Consequently, Human Ecology deals with the interrelationship between a human being or a number of human beings and the outside world surrounding him/her or them. For this purpose, a specific code was formulated:

System S1

> ***"Pattern of environmental relationships***
>
> *Totality of interrelationships between an "individual" or "ensemble" respectively and the outside world surrounding him/her or them"* (Knötig 1992b, p.6).

System S2

> ***"Individual** (single human being) **or ensemble** (a number of human beings)*
>
> *The interrelationships of whom with the outside world surrounding him/her or them are under consideration"* (Knötig 1992b, p.6).

System S3

> ***"Surroundings (surrounding outside world)***
>
> *That part of the world (understood as the totality of all that is considered to be "existing") that remains, when this respective "S2" is cut out"* (Knötig 1992b, p.6).

Human ecology offers several concepts to deal with these interactions. One of these concepts is the pair of ecological potency and ecological valency. (Knötig 1992a, Knötig 1992b) They are defined as the following:

Ecological potency (ec.pot.):

> *"Totality of the characteristics of human being or an ensemble of human being ("S2") in their distinctions realized at the respective point in time, considered in their significances in the encounter with his/her of their surroundings ("S3")"* (Knötig 1992b, p.3).

Ecological valency (ec.val.):

> *"Totality of the characteristics of an "S3" in their distinctions realized at the respective point in time, considered in their significance for the related "S2""* (Knötig 1992b, p.3).

In other words, ecological potency refers to the ability of people to interact with the surrounding world. Ecological valency looks at the totality of the surrounding worlds characteristics (Mahdavi 2018)

Some contributions from the psychologist Gibson also deal with the interactions of living beings and their surroundings (Gibson 1977, Gibson 1986). He defined the concept of "affordance" and explains it as the following:

"Affordance of the environment are what it offers the animal, what it provides or furnishes" (Gibson 1986, p.127).

This concept also offers similarities to Uexküll's work (Uexküll 1920, Mahdavi 2016).

Another pair of concepts of the human ecology are material-energetic and information related aspects.

Material-Energetic Aspect (m.e. aspect):

> *"There is nothing that is called "existing" in a scientific manner (no entity, no state, no process) unlessan amount of matter and/or energy differing from "zero" is involved. The "material-energetic aspect" is related to this amount of matter/energy"* (Knötig 1992b, p.9).

Informatory Aspect (inf. aspect):

> *"Matter/energy necessarily has a certain distribution in space and time. The particular distribution may be understood as a structure. To this structure one can correlate an "information content" (in "bits"). However, that is not to say that this structure can be completely described by its respective information content. This distribution, structure or information content is regarded as being correlated with the "informatory aspect"* (Knötig 1992b, p.9).

Individualdistanz Scheme and G.I.A.S

The Individualdistanz Scheme is illustrated in Figure 2. The symbols used in this figure are explained in the legend which is shown in Figure 1. The Individualdistanz Scheme was designed to see for what kind of circumstances a person is affected by an event in its surrounding so that in case of an unwanted or important event it can lead to a course of action. For example, a dangerous situation can be meant with the term “unwanted event”.

The Individualdistanz Scheme was developed to get to the General Inter-Action Scheme, or G.I.A.S. This Scheme is shown in Figure 3. Its legend can be found in Figure 1 as well. It should be mentioned that the General Inter-Action Scheme should be used only in dynamic sense (Knötig 1992b).

Legend for fig. 1 (Individualdistanz Scheme) and fig. 2 (G.I.A.S.)

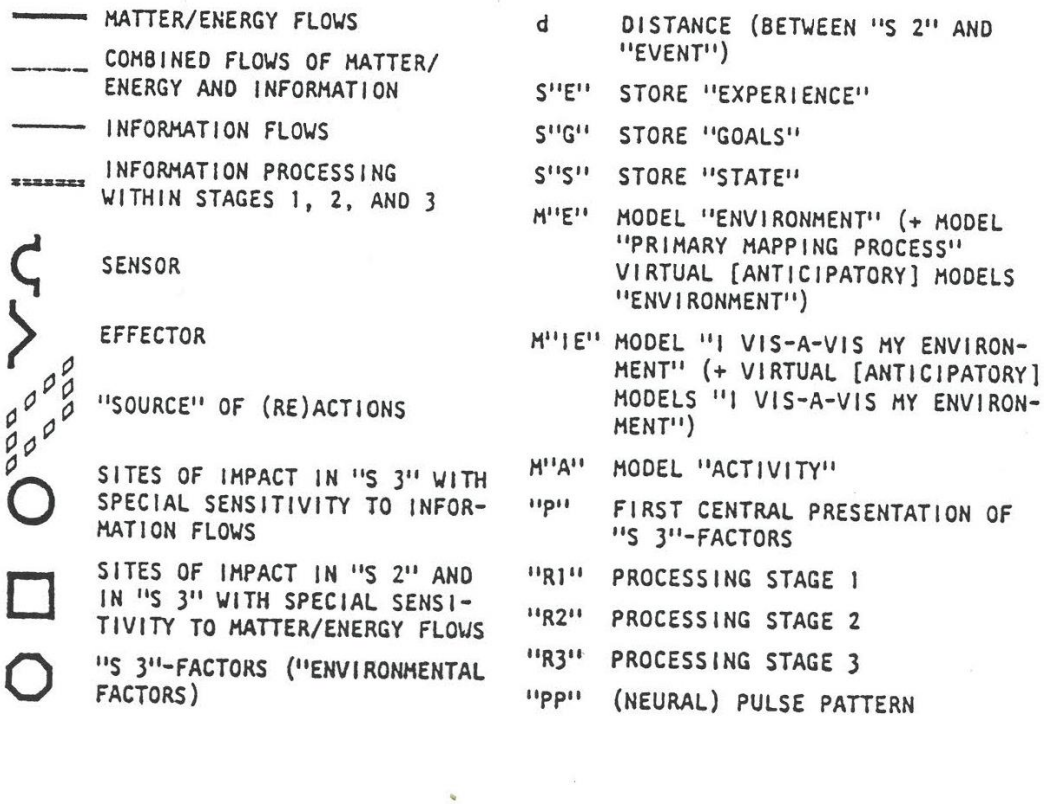

Figure 1 Legend Individualdistanz Scheme and G.I.A.S (Knötig 1992b)

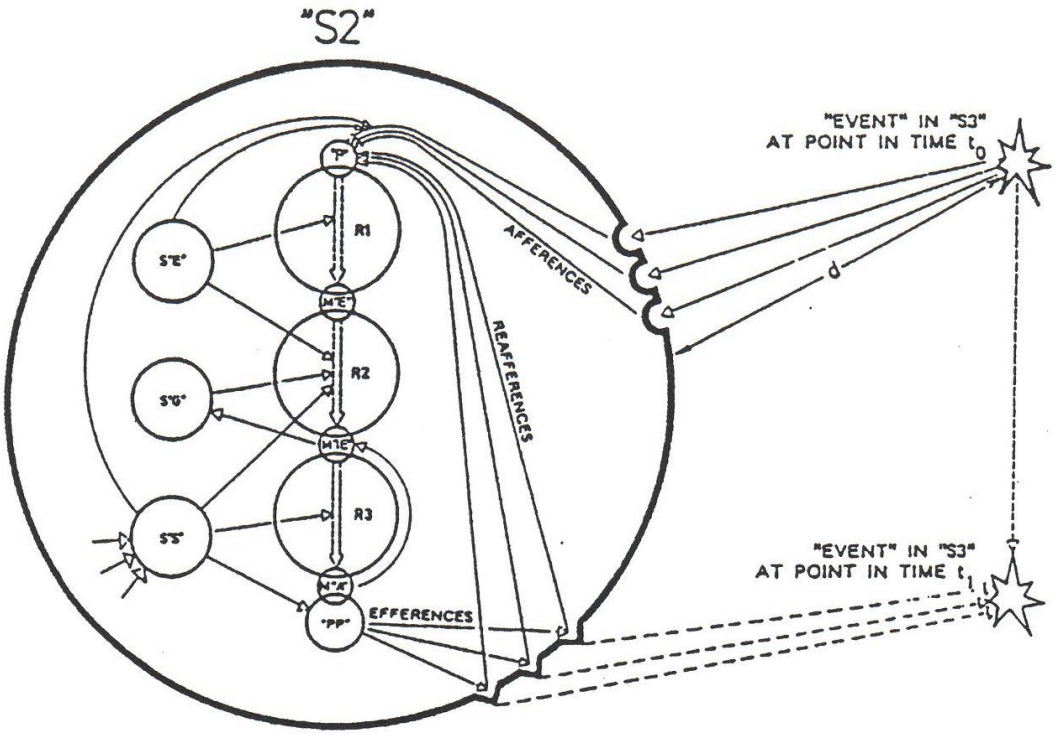

Figure 2 Incdividualdistanz Scheme (ID-S) (Knötig 1992b)

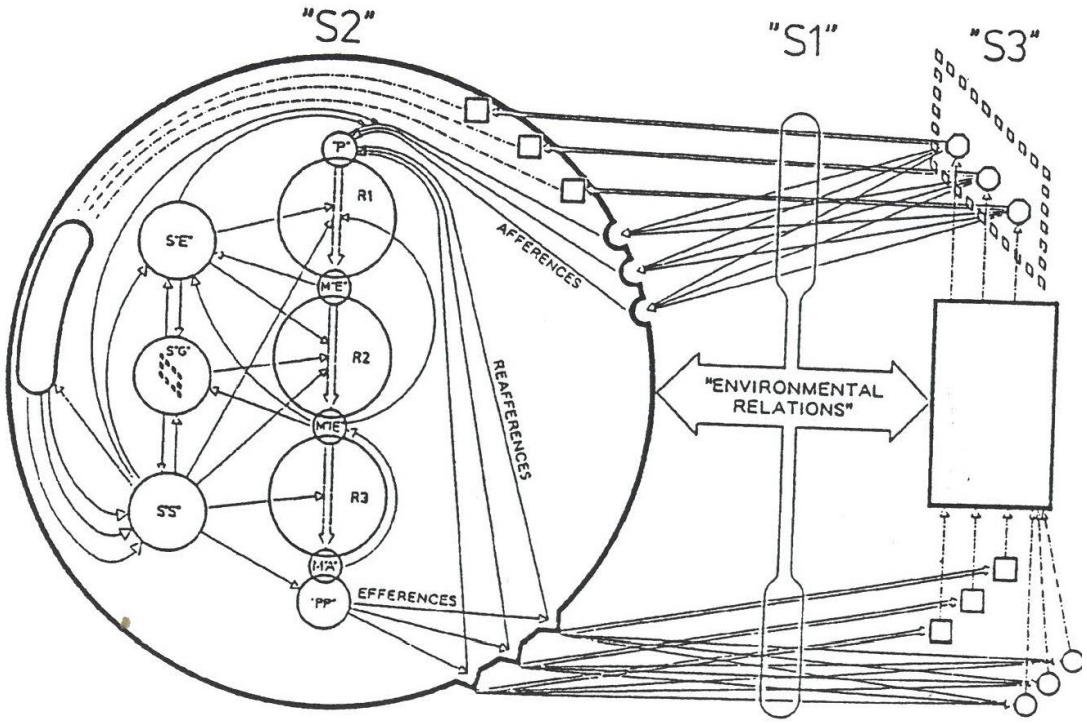

Figure 3 General inter-Action Scheme (G.I.A.S) (Knötig 1992b)

2.2 Previous efforts pertaining an ecological valency evaluation method

2.2.1 Potential, limits and challenges

Some contributions (Mahdavi 2018, Mahdavi and Berger 2019) deal with the certification potential of built environments' affordance. These two papers give preliminary reflections on the potential of designing and implementing an evaluation method for buildings' indoor environmental control devices and their human interfaces. Furthermore, the associated challenges of such a certification procedure are discussed as well. The following chapter gives an overview about the content of those contributions.

Implementing an ecological valency evaluation method raises multiple challenges. One of them is the fact that a strategy to simultaneously address the variance of inhabitants' ecological potency as well as indoor environments' ecological valency is needed. Commonly, (e.g. for thermal comfort requirements in buildings) an "average" building user is assumed as the reference. This is usually a healthy adult. However, this approach is not satisfactory. Including a higher diversity of inhabitant's ecological potency is definitely preferable. Nevertheless, it is likely that all occupants benefit from an improvement of the ecological valency by offering a wide a flexible range of conditions.

For the creation of an ecological valency evaluation method, it is useful to consider a couple of background factors. These can include the climatic context, building type or the room function (Mahdavi 2018, Mahdavi and Berger 2019). An appropriate unit of observation should also be defined. This could be a room, which can be assessed regarding the affordance (Mahdavi and Berger 2019). For this purpose, the availability as well as the attributes of the control devices can be assessed in a first approximation.

Mahdavi and Berger (2019) provide an illustrative taxonomy showing a selection of buildings' control devices and their associated mechanisms to influence the indoor environment. This taxonomy can be found in Table 3. Here, the symbol "✓" represents the main process mode. "○" is used for the secondary process mode or side effect. "–" stands for no impact.

Table 3 Illustrative taxonomy including control devices of a building and their associated processes (Mahdavi and Berger 2019)

DEVICES	Radiative energy modulation	Lighting modulation	Convective energy modulation	Air flow modulation	Humidity control
window	○	○	○	✓	○
exterior shades	✓	○	—	—	—
interior shades	○	✓	—	—	—
radiator	✓	—	○	—	—
radiant ceiling	✓	—	○	—	—
floor heating	✓	—	○	—	—
air diffusers	—	—	✓	✓	✓
humidifier	—	—	—	—	✓
illumination	○	✓	—	—	—
task lighting	○	✓	—	—	—
fan	—	—	—	✓	—
desk fan	—	—	—	✓	—

An example for a control device in a room is a window. It can regulate the magnitude of fresh air volume flow into a room. As a result, a window can influence the concentration of pollutants, the air quality but also the air temperature and humidity.

Evaluation of the ecological valency of a space should involve the availability and the quality of the control devices. Mahdavi and Berger (2019) state that these devices can be assessed according to five evaluation criteria. They are:

- **Spatial distribution**
  It should be assessed if the occupants can control the state of their surroundings. Furthermore, the spatial resolution level of the target zones are evaluated.

- **Objective effectiveness**
  This category deals with the objective effectiveness of the device. It looks at the fact if the device or element can fulfil the intended task in a satisfactory way.

- **Interface quality**
  The control devices are also assessed regarding the user interface. For example, it can be analyzed if the usability of the device is intuitive.

- **Subjective effectiveness**
  The degree of the subjective effectiveness of the element or device are examined as well. This category encompasses whether the occupants are satisfied with the devises' performance regarding its intended function.

- **Ecological quality**
  Here, it is evaluated if the device can be operated efficiently regarding the energy use and environmental impact.

Further challenges are for example assigning weighting factors to the different control devices as well to the rooms (Mahdavi and Berger 2019).

2.2.2 Student project

Human Ecology is a lecture at TU Wien, held by Univ. Prof. Dr. Ardeshir Mahdavi, assisted during the winter semester 2016 and 2017 by Dr. Farhang Tahmasebi (BST 2018). In this framework, students were asked to come up with their own attempts for an ecological valency evaluation method. Subsequently, they tested their method for a couple of spaces.

The following chapter presents one of the ideas and the outcome from this exercise.

Do Carmo and Vidal (2017) designed a questionnaire as well as an ecological valency index proposal for the Human ecology lecture.

In a first step, the developed questionnaire was used to ask occupants of three different spaces. The participants answered fourteen different questions within this questionnaire. These were related to four main categories. The first one is about temperature and temperature control. Subsequently questions about the air quality were asked. The other two categories are noise and artificial lighting.

In a next step the ecological valency evaluation method was designed. Do Carmo and Vidal (2017) chose to evaluate five different types:

- Temperature
- Natural Lighting
- Artificial Lighting
- Natural Ventilation
- Mechanical Ventilation

They decided to assess those types depending on three characteristics. They are:

- Type of control
- Spatial Resolution
- Efficiency of control

Their presented structure for this evaluation method is illustrated in Figure 4-6. It also includes the selected scoring system.

Type of Control			
	No Control	On/Off	Intensity
	1 Pts	2 Pts	3 Pts
Temperature			
Natural lighting			
Artificial lighting			
Natural ventilation			
Mechanical ventilation			
		T.C. Points	**SUM**

Figure 4 Students' concept:evaluation method type of control (Do Carmo and Vidal 2017)

Spatial Resolution			
	One Zone	Multiple Zones	Individual Zone
	1 Pts	2 Pts	3 Pts
Temperature			
Natural lighting			
Artificial lighting			
Natural ventilation			
Mechanical ventilation			
		S.R. Points	**SUM**

Figure 5 Students' concept:evaluation method spatial resolution (Do Carmo and Vidal 2017)

Eficiency of control			
	Existance	Effectiveness	Simplicity
	1 Pts	1 Pts	1 Pts
Temperature			
Acoustic			
Natural lighting			
Artificial lighting			
Natural ventilation			
Mechanical ventilation			
		E. C. Points	**SUM**

Figure 6 Students' concept:evaluation method efficiency of control (Do Carmo and Vidal 2017)

Furthermore, the designed structure was tested for three different buildings. Figure 8 shows the results for one of them. This space is used as a gym. In Figure 7 the floor

plan of the rooms is illustrated. The controllable devices and their associated control zones are marked (Do Carmo and Vidal 2017).

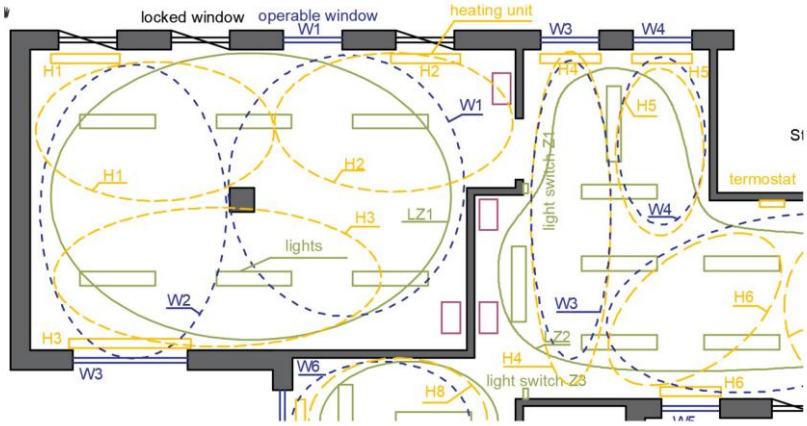

Figure 7 Students' concept 1: floor plan gym (Do Carmo and Vidal 2017)

Gym			
Type of Control			
	No Control	On/Off	Intensity
	1 Pts	2 Pts	3 Pts
Temperature			3
Natural lighting	1		
Artificial lighting		2	
Natural ventilation			3
Mechanical ventilation	1		
		T.C. Points	10
Spatial Resolution			
	One Zone	Multiple Zones	Individual Zone
	1 Pts	2 Pts	3 Pts
Temperature		2	
Natural lighting	1		
Artificial lighting		2	
Natural ventilation		2	
Mechanical ventilation	1		
		S.R. Points	8
Eficiency of control			
	Existance	Effectiveness	Simplicity
	1 Pts	1 Pts	1 Pts
Temperature	1	1	1
Natural lighting	0	0	0
Artificial lighting	1	1	1
Natural ventilation	1	1	1
Mechanical ventilation	0	0	0
		E. C. Points	9

Figure 8 Students' concept: result gym (Do Carmo and Vidal 2017)

2.2.3 WELL Building Standard

The WELL Building Standard is a rating system that focuses on humans' health, well-being and comfort in buildings (Wellcertified 2018). As part of this system, various aspects of a space are assessed. These are for example the air quality, lighting design, water quality, but also the health and wellness awareness of occupants. The WELL Building Standard is not an ecological valency evaluation method. However, within this assessment a few devices and elements with regards to the controllability of the indoor environmental conditions are considered. An example is the controllability of windows. For this reason, a short overview about this standard is given in this section.

Different versions of this system are available. The WELL Building Standard v1 can be used for commercial and institutional buildings. Apart from this version, some pilot programs are offered as well. They are applicable for other building types, such as for example multifamily residences or restaurants (Wellcertified 2018).

WELL v1

WELL Building Standard v1 was launched in October 2014. It can be used for the following three project types:

- New and Existing Buildings
- New and Existing Interiors
- Core and Shell

Each building or interior space is evaluated based on seven different categories. They are:

- Air
- Water
- Nourishment
- Light
- Fitness
- Comfort
- Mind

These categories encompass the evaluation of 105 different features. A selection is provided in Table 4. Within this table two abbreviations are used. "P" stands for

precondition. All categories that are marked as a precondition need to be achieved. Otherwise, a certification can not be received. The letter “O” stands optimization. A higher level of achievement (e.g. Platinum or Gold Certification) is possible by fulfilling conditions from these optimization categories (Wellcertified 2018).

Table 4 WELL Building Standard: selection of features (Wellcertified 2018)

		Core and Shell	**New and Existing Interiors**	**New and Existing Buildings**
Air	Air quality standards	P	P	P
	Smoking ban	P	P	P
	Ventilation effectiveness	P	P	P
	Humidity control		O	O
	Operable windows	O	O	O
Water	Fundamental water quality	P	P	P
	Water treatment	O	O	O
Nourishment	Fruits and vegetables		P	P
Light	Visual lighting design		P	P
	Low-glare workstation design		O	O
Fitness	Interior fitness circulation	P	O	P
	Fitness equipment	O	O	O
Comfort	Thermal Comfort	P	P	P
	Sound reducing surfaces		O	O
	Individual thermal control		O	O
Mind	Heath and wellness awareness	P	P	P
	Healthy sleep policy		O	O
	Stress and addiction treatment		O	O

These 105 features can be performance-based standards. Here, certain thresholds need to be met. An example are the categories “visual lighting design” or “air quality”. The features can also be prescriptive standards. In this case, certain tasks or design strategies need to be performed. For the feature “health and wellness awareness” no thresholds are given. Here, a specific task has to be fulfilled. In this case, literature about health and wellness must be provided for the occupants (Wellcertified 2018).

Table 5 illustrates how many preconditions or optimizations need to be achieved to receive a specific certification.

Table 5 WELL Building Standard: level of achievement (Wellcertified 2018)

Standard version	Level of achievement	Preconditions that must be achieved	Optimizations that must be achieved
WELL Building Standard	Silver Certification	All applicable	None
	Gold Certification	All applicable	40 % of applicable
	Platinum Certification	All applicable	80 % of applicable
WELL Pilot Standards	Silver Certification	All applicable	20 % of applicable
	Gold Certification	All applicable	40 % of applicable
	Platinum Certification	All applicable	80 % of applicable

WELL v2

WELL v2 was launched in May 2018 as a pilot project (V2Wellcertified 2018). A new feature is that now all types of buildings can be evaluated. However, a prerequisite is that at least 75 percent of the building area is occupied. Another major difference to the WELL Building Standard v1 is that the seven evaluation categories have changes to ten. The new ten concepts are:

- Air
- Water
- Nourishment
- Light
- Movement

- Thermal Comfort
- Sound
- Materials
- Mind
- Community

The category “Materials” was in the previous version part of the “Air” and “Mind” concepts. “Community” is a completely new category. Furthermore, the category “Comfort” from the original version was divided into “Thermal Comfort” and “Sound”. (V2Wellcertified 2018) In Table 6 a selection of the features from the new categories is provided. Again, two abbreviations are used within this table. “P” stands for precondition. The letter “O” means optimization

Table 6 WELL v2: selection features (V2Wellcertified 2018)

		Precondition/Optimization
Thermal Comfort	Thermal Performance	P
	Thermal Comfort Monitoring	O
	Humidity Control	O
Sound	Sound Mapping	P
	Maximum Noise Levels	O
	Sound Barriers	O
Materials	Fundamental Material Precautions	P
	Outdoor Structures	P
	Waste Management	O
Community	Integrative Design	P
	Occupant Survey	P

3 ECOLOGICAL VALENCY EVALUATION METHOD

This Chapter presents a specific attempt for the structure of an ecological valency evaluation method. It builds upon and extends previous ideas developed at the Department of Building Physics and Building Ecology of TU Vienna (Mahdavi 2018, Mahdavi and Berger 2019, Mahdavi 2016) Its goal is to assess the controllability of the indoor environmental conditions for occupants. This method intends to evaluate each room of a certain space individually. Subsequently, the outcome of the different rooms can be combined to get to an overall EVI (Ecological Valency Index) for the building.

Evaluation method room:

Figure 9 shows the general structure of the evaluation method for a room. Depending for example on the location of the building and other various aspects, this structure can be defined in more detail. Thus, categories and attributes have to be chosen to adjust this protocol to the climatic context or usage of the building.

Consider the case of buildings located in countries with a warm climate during summer and winter. The occupants will have specific needs regarding the performance and availability of certain control devices. In this case, offering a heating system is not as important. But rooms equipped with a good and effective shading system can provide a much better indoor environment for the occupant. Therefore, in case buildings are evaluated in such a climatic context, shading or cooling systems should be rated higher than heating systems.

To perform the evaluation of a room, the devices and elements that should be included have to be defined. They are the main categories of this evaluation method. Each device is evaluated in two parts.

<u>Part one:</u>

The first part deals with the availability of the device or element and its functions. It is assessed if the device can be found in the space but also to which degree, it can be controlled by the user. Devices that offer certain functionalities are rewarded with points. These points can be given depending on the importance of the function. It is recommended that the sum of the maximum possible points from part one is the same for each device. The reason is a better comparison of the performance of the

operational equipment. Weighting factors can be included later, in case some of the devices can be seen as more important than others.

Room: Number of people: Area [m²]:

device 1		max. points	points		p1: poor m1: okay g1: good	points part 1 + part 2	∑ x w1
	attribute 1.1	x1		spatial distribution			
	attribute 1.2	y1		objective effectiveness			
	attribute 1.3	z1		interface quality			
	...	...		subjective effectiveness			
	...	...		ecological quality			
	∑ part 1			∑ part 2			

device 2		max. points	points		p2: poor m2: okay g2: good	points part 1 + part 2	∑ x w2
	attribute 2.1	x2		spatial distribution			
	attribute 2.2	y2		objective effectiveness			
	attribute 2.3	z2		interface quality			
	...	...		subjective effectiveness			
	...	...		ecological quality			
	∑ part 1			∑ part 2			

device 3		max. points	points		p3: poor m3: okay g3: good	points part 1 + part 2	∑ x w3
	attribute 3.1	x3		spatial distribution			
	attribute 3.2	y3		objective effectiveness			
	attribute 3.3	z3		interface quality			
	...	...		subjective effectiveness			
	...	...		ecological quality			
	∑ part 1			∑ part 2			

...		max. points	points		...	points part 1 + part 2	...
	...	...		spatial distribution			
	...	...		objective effectiveness			
	...	...		interface quality			
	...	...		subjective effectiveness			
	...	...		ecological quality			
	∑ part 1			∑ part 2			

device n		max. points	points		pn: poor mn: okay gn: good	points part 1 + part 2	∑ x wn
	attribute n.1	xn		spatial distribution			
	attribute n.2	yn		objective effectiveness			
	attribute n.3	zn		interface quality			
	...	...		subjective effectiveness			
	...	...		ecological quality			
	∑ part 1			∑ part 2			

Room EVI	

Figure 9 Structure ecological valency evaluation method room

Part two:

The second part focuses on the performance of the devices in five categories. They are also part of a publivation by Mahdavi and Berger (2019). Thes categories are presented more in detail in chapter 2.2.1 and include:

- Spatial distribution
- Objective effectiveness
- Interface quality
- Subjective effectiveness
- Ecological quality

The devices or elements of each room are to be assessed depending on those categories. This is done through assigning points to these categories. Three different options are possible. They capture the performance of the device in three levels, namely poor, acceptable, good. Points can be assigned to these three possibilities.

Weighting Factors:

The obtained points from part one and part two are added for each device. It can occur that some of the evaluated elements and devices can be considered as more important than others. Another possibility is that some might have a greater influence on the indoor environment. As a result, a weighting factor can be included for each device. The sum of the weighted points from the devices result in the overall EVI of the room.

Evaluation method building:

To receive the EVI of the overall building, another evaluation structure is provided. It is illustrated in Figure 10. This method uses the obtained points from the evaluation of each room. Additionally, there is the possibility to include a weighting factors. This can be done depending on the importance of the room. The calculation of this weighting factor can, for example, include the area of the room, or the number of people using it.

The Sum of the weighted points from the rooms result in the overall Ecological Valency Index of the building.

Rooms	Area [m²]	Number of people	weight (w)	Points (EVI)	EVI × w
Room 01	A1	p1	w1	EVI Room 01	
Room 02	A2	p2	w2	EVI Room 02	
Room 03	A3	p3	w3	EVI Room 03	
...	...	...	...	...	
Room n	An	pn	wn	EVI Room n	
∑					

Figure 10 Structure ecological valency evaluation method building

4 A CASE STUDY

4.1 Method

4.1.1 Overview

The ecological valency measurement protocol, which is presented in Chapter 3 was tested in an experiment. An office area in Vienna, Austria was selected to conduct this study. For this purpose, the structure of the evaluation protocol had to be supplemented to fit to the climatic context of the tested space. Therefore, the different categories had to be chosen. These include the control devices, their attributes and weighting factors.

Selected devices:

In a first step, the devices and elements were selected that were to be evaluated. In this case visual and hygro-thermal aspects as well as the quality of the air are the main focus of this evaluation method. It was decided to assess five categories of control equipment, for a building in such a location. They are:

- Windows
- Shading
- Lights
- Heating
- Cooling

By incorporating these five categories, hygro-thermal-, and visual aspects as well as the air quality of the space is incorporated in this method.

Part one:

Important attributes of the devices had to be defined for the first part of the evaluation. Offering of specific functionalities are awarded with points. Within this part, each device can receive a maximum of five points. The chosen attributes check the availability and the function of the devices.

An example is the category windows. Here, a room can get points for three characteristics. First, if windows are existent in the space, up to two points can be given. In case the window can be opened by offering a turn function the device gets an additional two points. For a tilt function of the window one extra point is added.

Part two:

The second component of this evaluation method is dedicated to the spatial distribution, objective and subjective effectiveness, interface quality and ecological quality of the operational equipment. Regarding the evaluation of those aspects a point system was chosen. A higher importance was given to the performance of the devices (part two) rather than their availability (part one). As a result, the devices can obtain the double amount of points for part two. Consequently, the maximum possible points for this part are ten.

In more detail, if a device is assessed in one of the categories as good, two points can be given. One point means the aspect was perceived as acceptable. Zero points represents a poor performance in the evaluated area. Choosing points between these specified numbers is also not prohibited (e.g. 1.5).

Weighting factor for the devices:

Some of the chosen devices can be assumed to have a higher influence or importance on the indoor environmental conditions of a room. As a result, weighting factors for the devices were added to the protocol. The experiment is conducted in Vienna, Austria. There, a heating system is needed during the majority of the year. As a result, it was rated as more important than cooling systems. While the weighting factor for the heating system is 1.65, the categories cooling and shading did not receive an additional weighting factor. The weighting factor for windows is 1.65 and for lights 1.35 was chosen.

In this case every room can get maximum of a hundred points. Figure 11 illustrates the protocol to assess the rooms of the office area.

Room: **Number of people:** **Area [m²]:**

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1

Room EVI	

Figure 11 Case study: evaluation method room

Weighting factor for the rooms:

To get to an Ecological Valency Index for the overall office area, additional weighting factors were used for each room. It includes the area of the room and the number of occupants. The weighting factor for the rooms w is calculated with Equation 1.

$$w\frac{A}{\sum A} \times 0.9 + \frac{n}{\sum n} \times 0.1 \qquad (1)$$

The Ecological Valency Index for the entire office area is the sum of the obtained points from each room multiplied with the weighting factor. In this case the maximum possible outcome is a hundred. The used protocol for the building is shown in Figure 12.

Rooms	Area [m²]	Number of people	weight (w)	Points (EVI)	EVI × w
Kitchen	12.8	2	0.07		
Office 01	46.6	7	0.27		
Office 02	9.2	1	0.05		
Office 03	36.5	1	0.19		
Office 04	11.5	1	0.06		
Meeting Room	56.1	20	0.36		
∑	172.7	32	1.00		

Figure 12 Case study: evaluation method building

About thirty people participated in this experiment. Their task was to go around the office area and fill an evaluation protocol for each room. Furthermore, they calculated the Ecological Valency Index for the overall office. The participants did these exercises individually. There are two reasons for this approach. On the one hand the usability of the method itself can be tested. On the other hand, the degree to which the different results could diverge when the same room is assessed by different participants can be documented.

Subsequently, the participants were asked to give feedback and suggestions about the tested evaluation method. Their task was to answer two questions. This should show whether understanding the protocol was easy and intuitive or difficult. Furthermore, they were asked if choosing points for the different categories caused difficulties. An optional section for written feedback was provided as well. Here, the participants had the opportunity to comment on the evaluation protocol in more detail. Figure 13 shows the feedback questions along with the possible answering options.

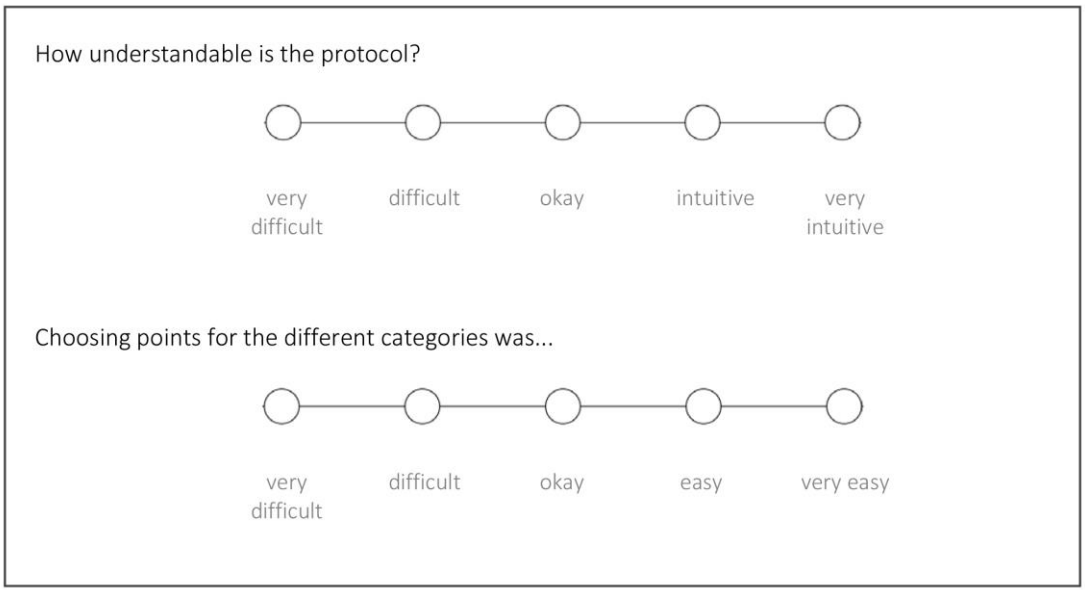

Figure 13 Office experiment Feedback questions

All of the documents that the participants received at the beginning of the experiment to perform the evaluation method are provided as well. They can be found within the Appendix 8.1.

4.1.2 Selected office area

The proposed evaluation method is tested for an office area in an educational building. This office is located in the fourth district of Vienna, Austria. Six different rooms of this building are used for the assessment. These include a kitchen, four office spaces and a meeting room. The corridor connecting the rooms is not assessed. While Figure 14 illustrates a floor plan of the office area, Table 7 shows the number of occupants and the area of the different rooms.

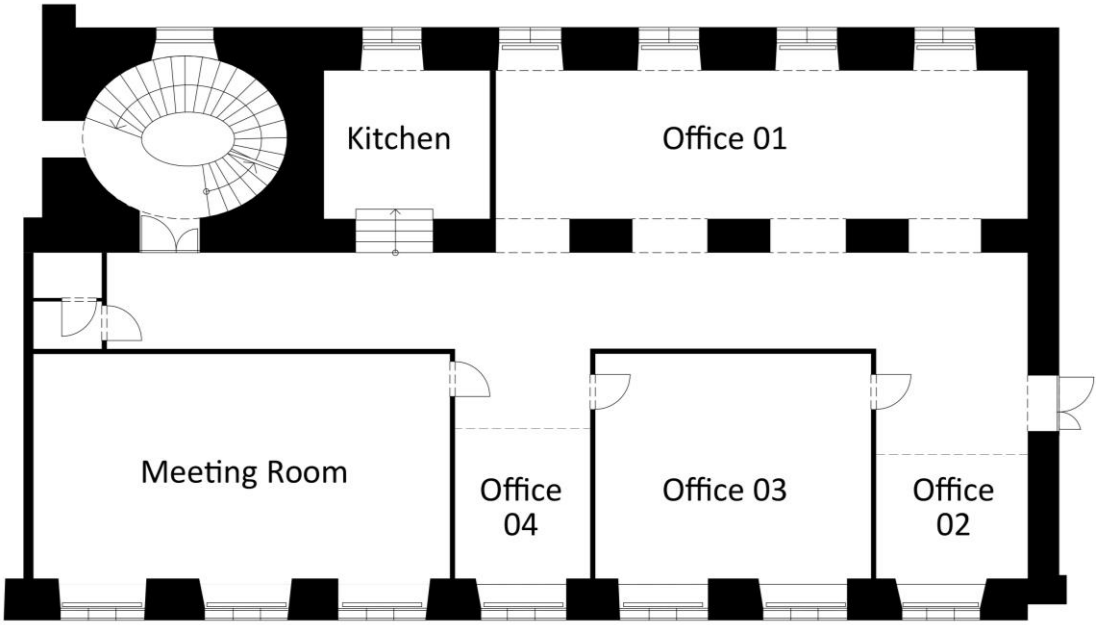

Figure 14 Floor plan office area

Table 7 Office Area Data

Room	Area [m²]	Number of occupants
Kitchen	12.8	2
Office 01	46.6	7
Office 02	9.2	1
Office 03	36.5	1
Office 04	11.5	1
Meeting Room	56.1	20

Figure 15-20 show more detailed floor plans of the individual rooms. The devises that have to be assessed are marked. Moreover, the associated control zones are schematically included. The position, of the light switches are illustrated as well.

Kitchen

The kitchen is one of the smaller rooms of the office area. It offers one window, which consists out of two separated layers. While the outer glass layer can be opened manually, the inner one is opened automatically after pressing a switch. It is next to the window. Blinds can be found between the two layers of the window.

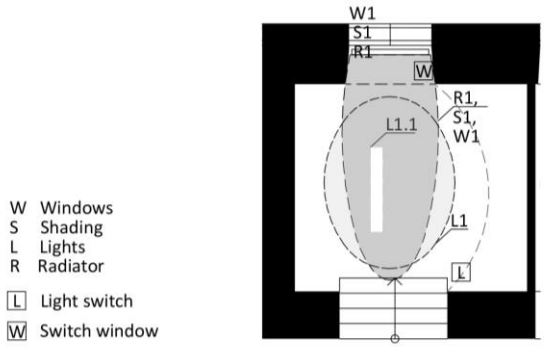

Figure 15 Kitchen: floor plan with devices and control zones

Office 01

The windows of Office 01 consist out of two glass layers (an interior and an exterior casement). They can be opened manually. A turn function as well as a tilt function is available. The radiators are in front of the window. Every desk is equipped with a task light.

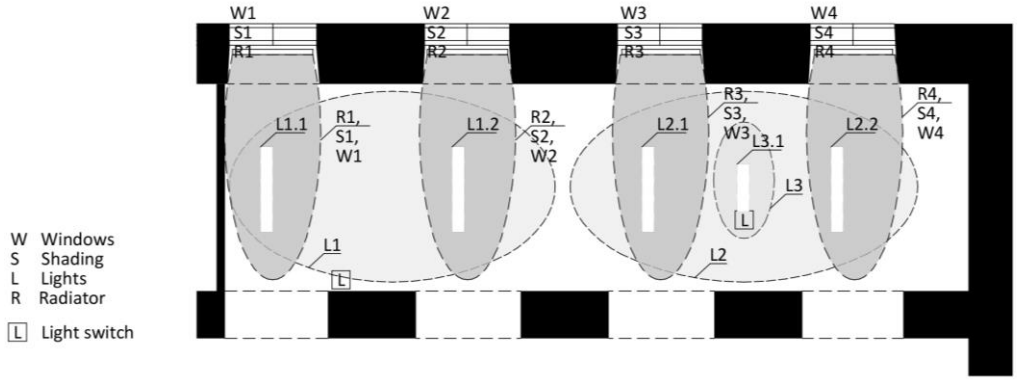

Figure 16 Office 01: floor plan with devices and control zones

Office 02

Office 02 is the smallest room of the office area. The windows are similar to the ones from Office 01. The shading system is located between the glass layers of the window. No task light is available. It is noticeable that the light switch for the ambient lighting is not very close to the work place.

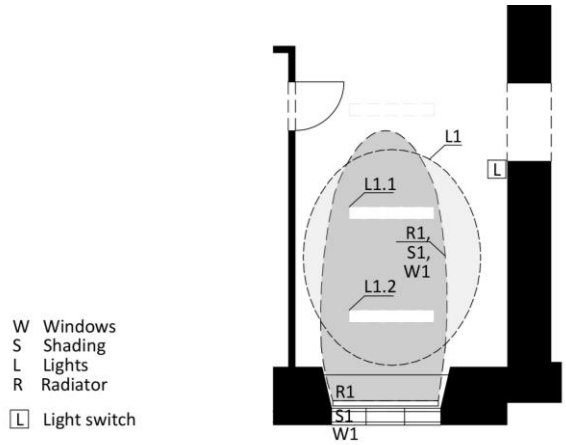

Figure 17 Office 02: floor plan with devices and control zones

Office 03

Office 03 features a variety in options to control the ambient lighting. The windows and shading system are similar to Office 01. Furthermore, radiators are located in front of the window.

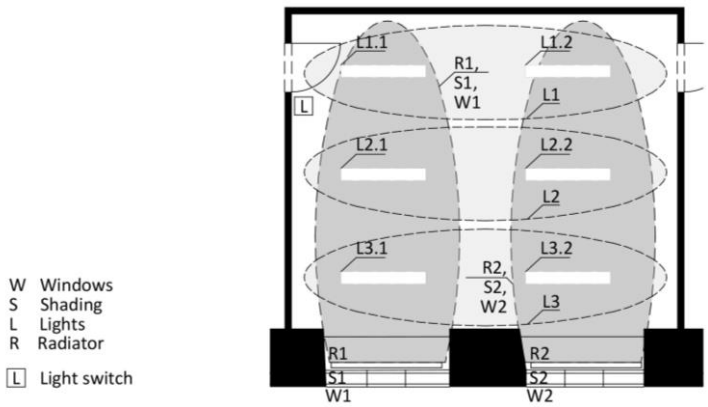

Figure 18 Office 03: floor plan with devices and control zones

Office 04

Office 04 is similarly organized to Office 02. An exception is the fact that in this case, a task light is offered. Furthermore, more options regarding the usage of the ambient lighting are available.

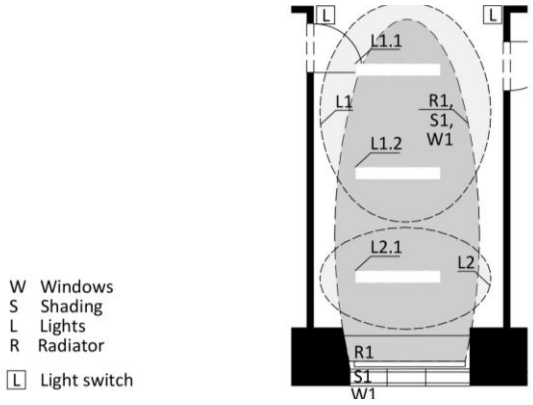

Figure 19 Office 04: floor plan with devices and control zones

Meeting Room

The windows of the Meeting Room are the same as the ones from Office 01. Moreover, there are no task lights available.

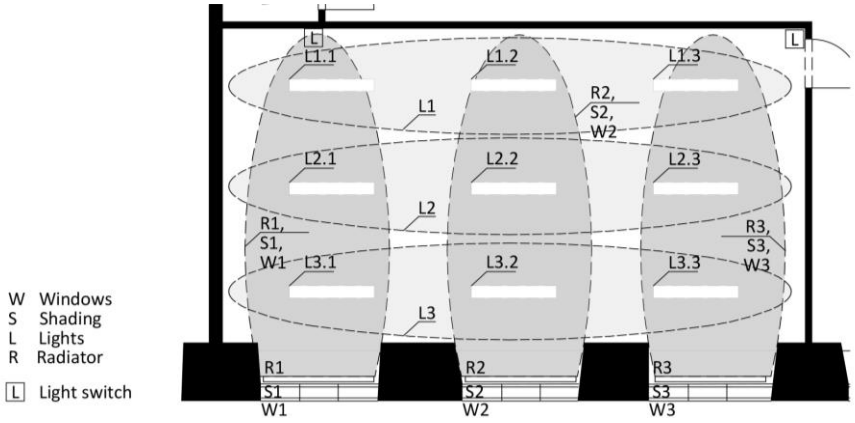

Figure 20 Meeting Room: floor plan with devices and control zones

4.1.3 Participants

In total, twenty-eight people participated in this experiment. Some of them were occupants of the office area. They know the space and have also used the control equipment to regulate the indoor environmental conditions. Others were visitors. They saw the office area for the first time at the experiment. The number of participants is shown in Table 8. Their gender, as well as whether they are an occupant or visitor is illustrated.

Table 8 Participants of the case study

	occupant	visitor	∑
female	5	14	**19**
male	3	6	**9**
∑	**8**	**20**	**28**

4.1.4 Research questions and hypotheses

After conducting the experiment, the data is analyzed within seven research questions. They are the following:

Q1 How did the participants evaluate part one?

The outcome of part one is examined. Special attention is paid to the degree to which the evaluation results of the participants diverge. The strategy is to analyze the mean, standard deviation as well as the coefficient of variance of the participants' results. Especially the latter indicator can express, the degree of variation.

Part one of the evaluation method deals with the availability of the control devices and its functions. It should be clearly visible whether a device is available in a room or can offer a certain functionality. Therefore, it is expected that assigning points should not be very challenging for the participants. Consequently, it is assumed that the results of the participating persons are rather similar.

Q2 How did the participants evaluate part two?

The second part of the presented case study is analyzed as well. The approach is similar to Q1. The focus lies on the degree to which participants' results differ. This is examined by considering the average answer of the participants, the standard deviation and particularly the coefficient of variance. Furthermore, the differences between part one and part two are analyzed.

In case of part two, wider variations regarding the selected points of the participants are expected, especially in comparison to part one. It is assumed that evaluating the performance of the device is a more subjective task, even though evaluation criteria and a point system is offered within the evaluation method.

Q3 Are there system related differences?

This research question deals with the results of the controllable elements or devices. Therefore, it looks at the windows, lights, shading-, heating-, and cooling systems of the office area. The achieved points of each control device is compared to the others. First of all, this is done for the devices in every room. Subsequently, the average points that each device received in the overall office area are analyzed and compared.

Q4 Are there room related differences?

Here, the Ecological Valency Index of each room is compared to every other room to look at possible differences. The outcome is illustrated through a boxplot.

Q5 Are there differences between the results of the occupants compared to the visitors?

It is analyzed to which degree the outcome of the occupants and the visitors diverge. This is achieved by comparing the results of each room and the overall office area. Moreover, the distribution of the resulting values from the participants as well as the mean outcome is illustrated in form of a boxplot.

Q6 Are there differences between the results of the female participants compared to the male participants?

The results of the female participants are compared to the ones of the male participants. Similar to Q5, the results of the different rooms and the overall office area should be used for this comparison. A boxplot shows the distribution of the results, as well as the minimum, maximum and mean values.

Q7 What is the feedback from the participants?

The feedback questions are analyzed to evaluate the usability and understandability of the method. Furthermore, the written statements from the participants are discussed.

4.2 Results

4.2.1 Overview

The outcome of the case study can be found in this chapter. It shows the most significant results based on the research questions, which are presented in chapter 4.1.4. A more detailed set of results is illustrated in the Appendix 8.2 – 8.3.

It has to be stated that none of the evaluated rooms offer an installed cooling system. For this reason, the category cooling is not included in the results that are presented this chapter.

4.2.2 Evaluation of the first part

Table 9 shows the results of the first part of the evaluation method. It provides information about the numeric evaluation results in terms of mean, standard deviation and the coefficient of variation (in percent).

Table 9 Results evaluation method part 1

		Windows	Shading	Lights	Heating
Kitchen	mean	4.14	2.14	3.04	4.23
	standard deviation	0.35	0.44	0.19	0.41
	coefficient of variation	8.45	20.55	6.11	9.72
Office 01	mean	4.48	2.25	3.89	4.20
	standard deviation	0.56	0.67	0.49	0.39
	coefficient of variation	12.47	29.99	12.55	9.20
Office 02	mean	4.68	2.13	3.14	4.20
	standard deviation	0.47	0.41	0.35	0.39
	coefficient of variation	9.98	19.51	11.13	9.20
Office 03	mean	4.55	2.13	3.46	4.20
	standard deviation	0.47	0.41	0.55	0.39
	coefficient of variation	10.31	19.51	15.87	9.20
Office 04	mean	4.70	2.09	3.79	4.20
	standard deviation	0.45	0.27	0.49	0.39
	coefficient of variation	9.58	12.88	12.94	9.20
Meeting Room	mean	4.77	2.09	3.13	4.20
	standard deviation	0.39	0.27	0.49	0.39
	coefficient of variation	8.16	12.88	15.78	9.20

4.2.3 Evaluation of the second part

The outcome of the second part is illustrated in Table 10. The table provides again information about the numeric evaluation results in terms of mean, standard deviation and the coefficient of variation (in percent). These values can be seen for each control device in every evaluated room.

Table 10 Results evaluation method part 2

		Windows	Shading	Lights	Heating
Kitchen	mean	6.89	6.89	7.14	7.24
	standard deviation	1.73	1.38	1.87	1.49
	coefficient of variation	25.15	19.99	26.18	20.58
Office 01	mean	7.82	6.93	8.13	7.31
	standard deviation	1.26	1.44	1.38	1.33
	coefficient of variation	16.05	20.84	16.98	18.12
Office 02	mean	7.07	7.02	7.39	7.82
	standard deviation	1.27	1.32	1.71	1.32
	coefficient of variation	18.00	18.80	23.17	16.85
Office 03	mean	7.64	7.21	8.32	7.78
	standard deviation	1.19	1.30	0.89	1.30
	coefficient of variation	15.62	18.00	10.68	16.69
Office 04	mean	7.38	7.01	7.76	7.52
	standard deviation	1.27	1.33	1.29	1.24
	coefficient of variation	17.25	19.00	16.66	16.43
Meeting Room	mean	7.80	7.20	8.46	7.29
	standard deviation	1.25	1.29	0.99	1.51
	coefficient of variation	16.00	17.94	11.70	20.70

4.2.4 System-wise evaluation

The points that, each system received during the experiment are shown in this section. Figure 21, 23, 25, 27, 29 and 31 illustrate the outcome in form of a boxplot. Figure 22, 24, 26, 28, 30, 32 and 33 show a more detailed visualization of the devices' performance in part two. For a better comparison, the results are shown without including any kind of weighting factors.

Kitchen:

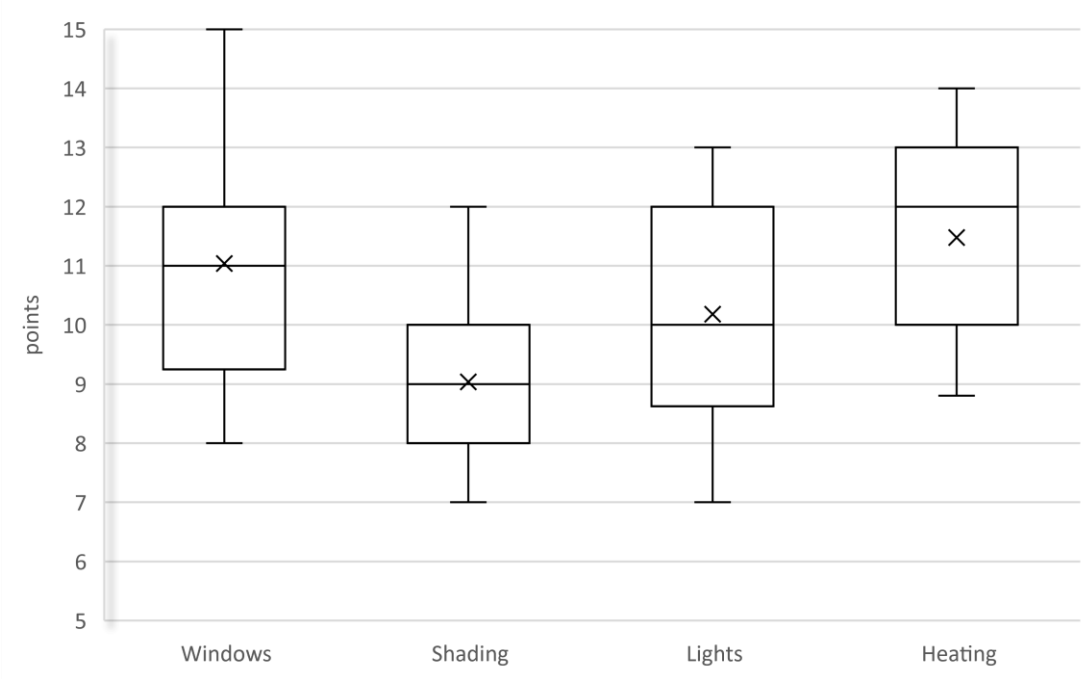

Figure 21 Boxplot: control devices kitchen (points from part 1 and part 2)

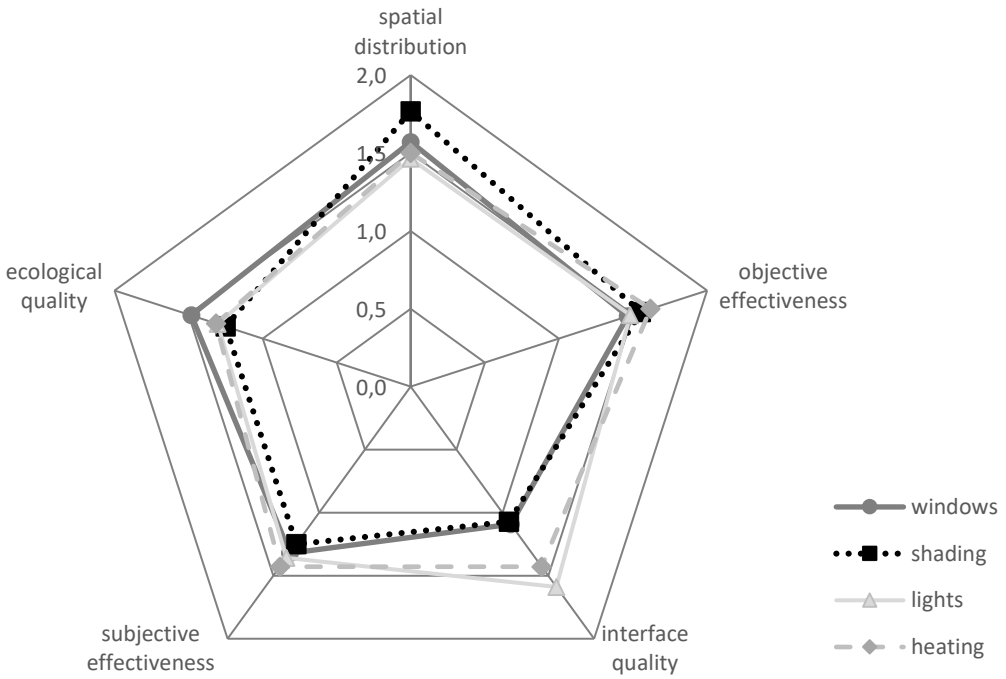

Figure 22 Results control devices kitchen (part 2)

Office 01:

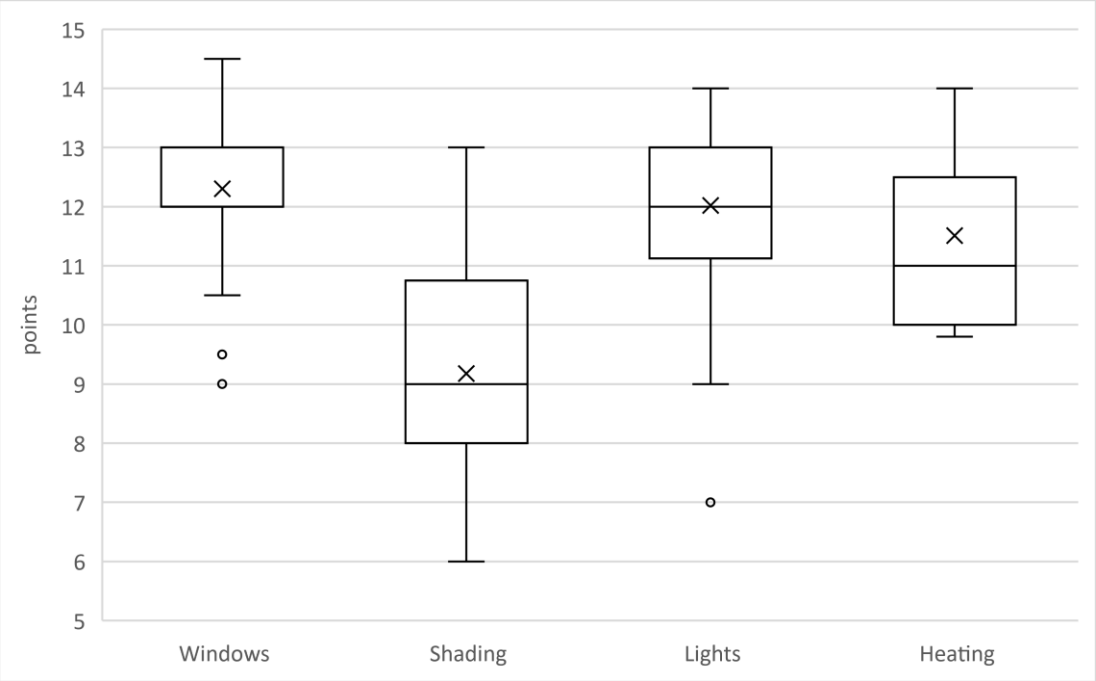

Figure 23 Boxplot: control devices office 01 (points from part 1 and part 2)

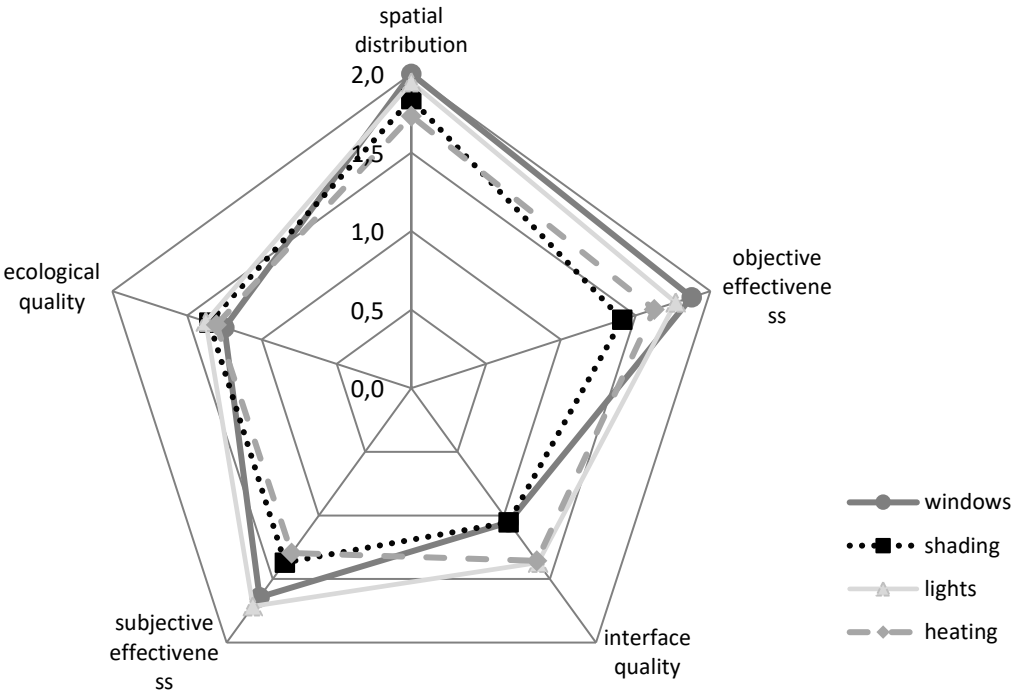

Figure 24 Results control devices office 01 (part 2)

Office 02:

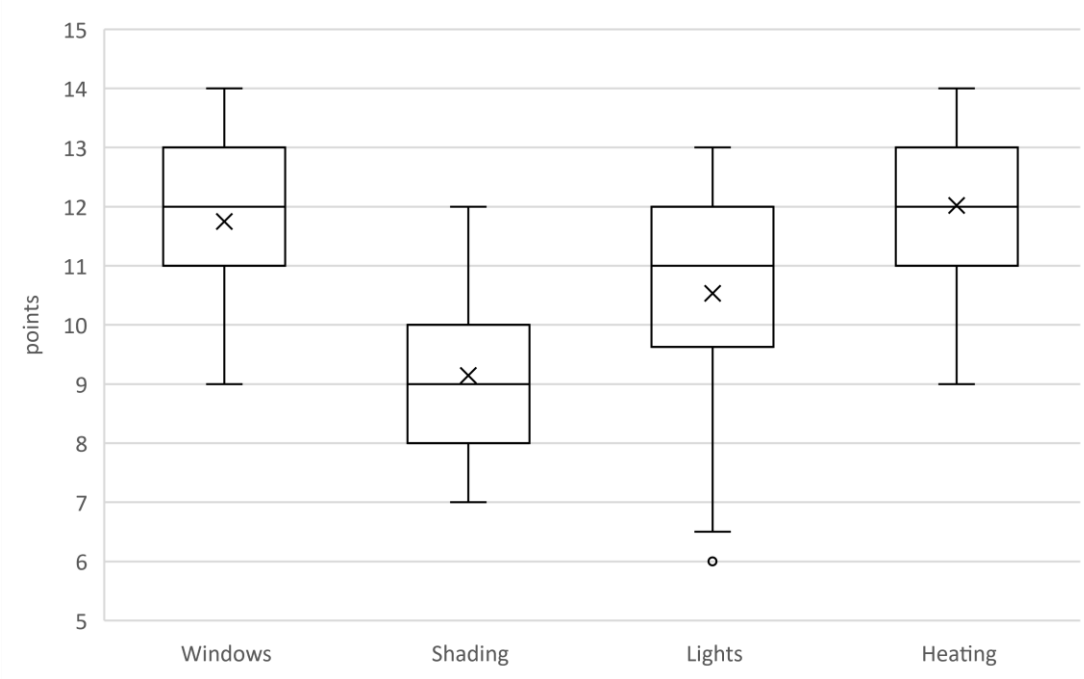

Figure 25 Boxplot: control devices office 02 (points from part 1 and part 2)

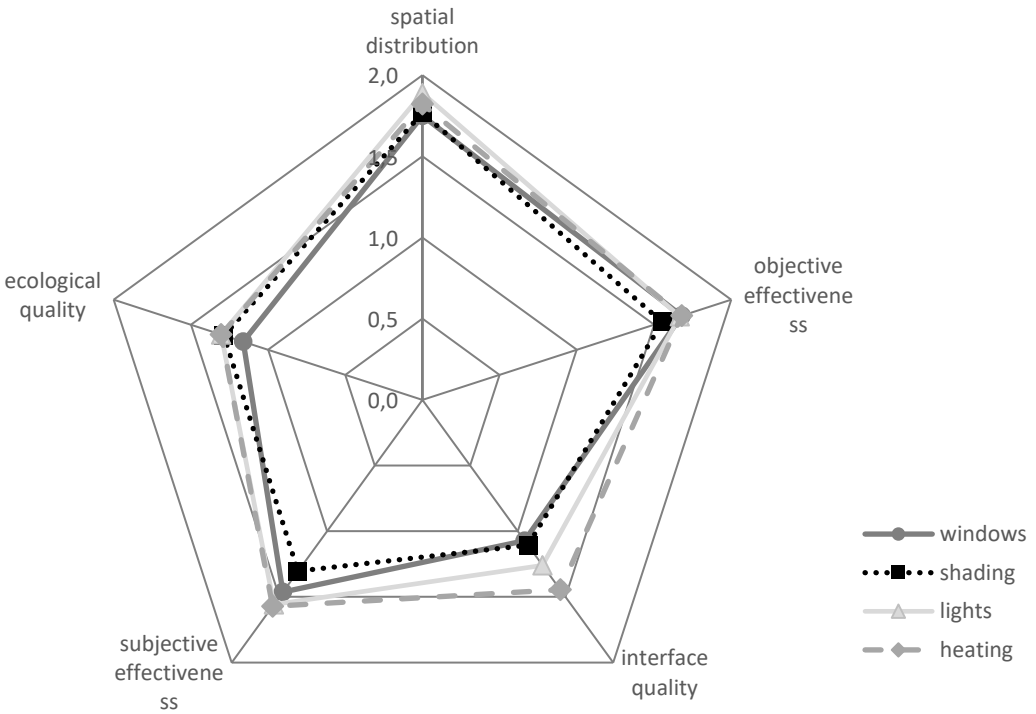

Figure 26 Results control devices office 02 (part 2)

Office 03:

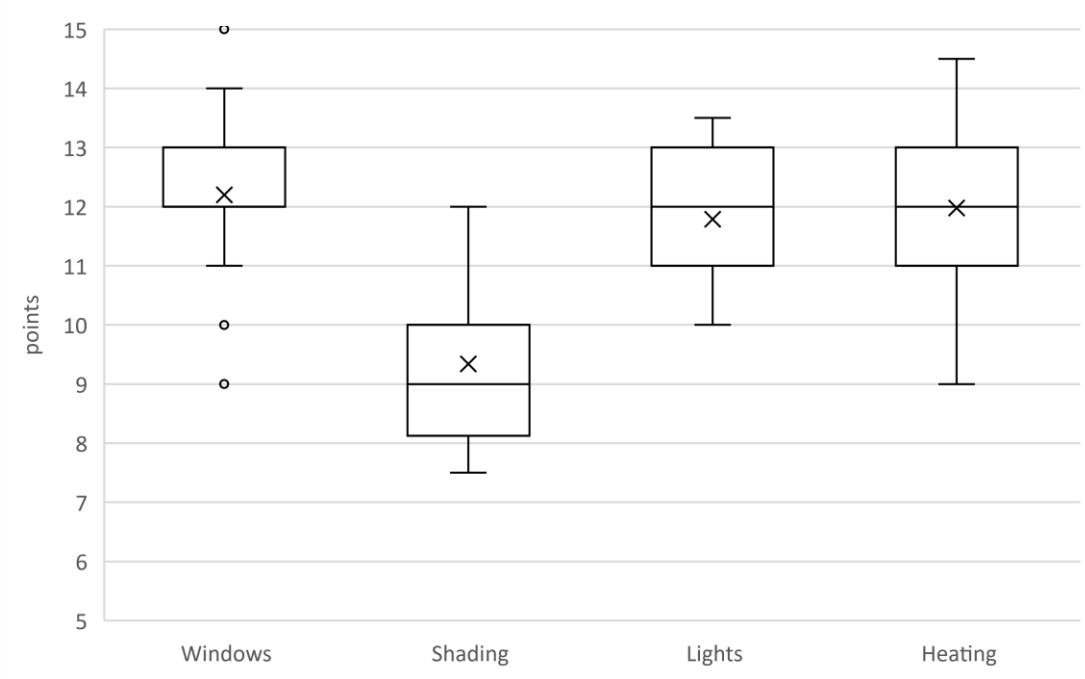

Figure 27 Boxplot: control devices office 03 (points from part 1 and part 2)

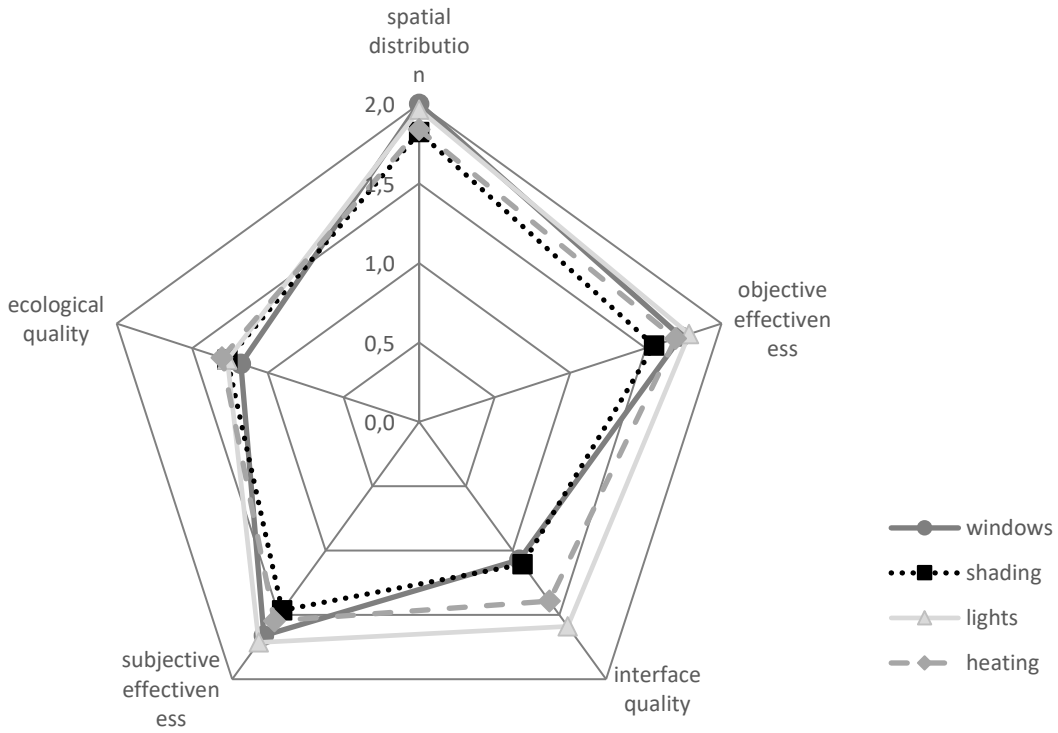

Figure 28 Results control devices office 03 (part 2)

Office 04:

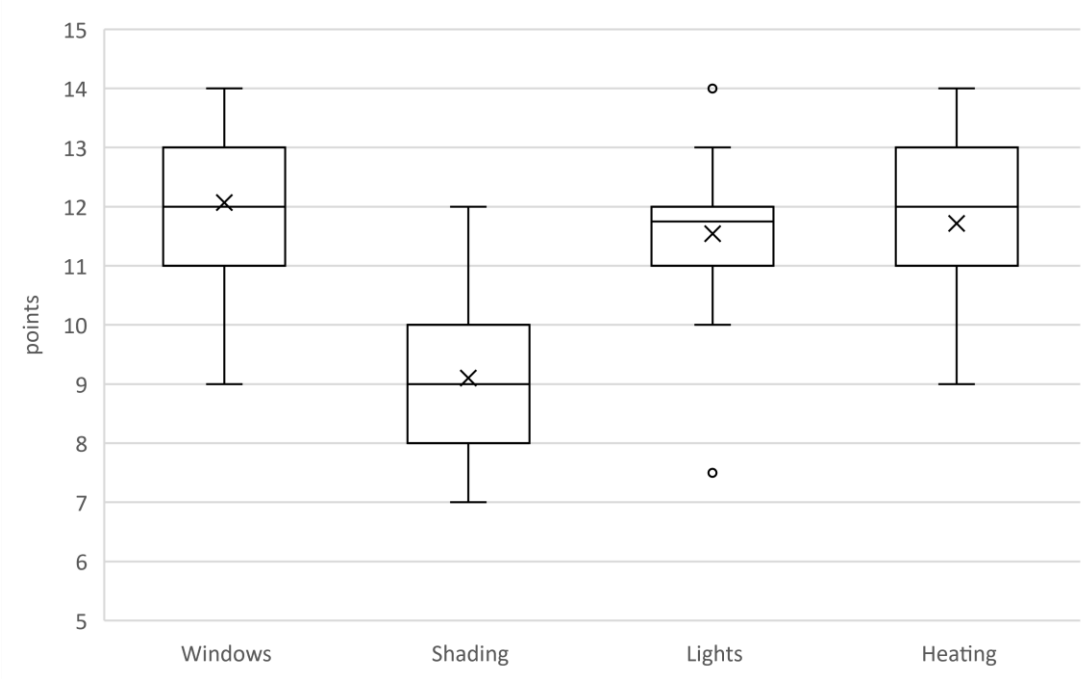

Figure 29 Boxplot: control devices office 04 (points from part 1 and part 2)

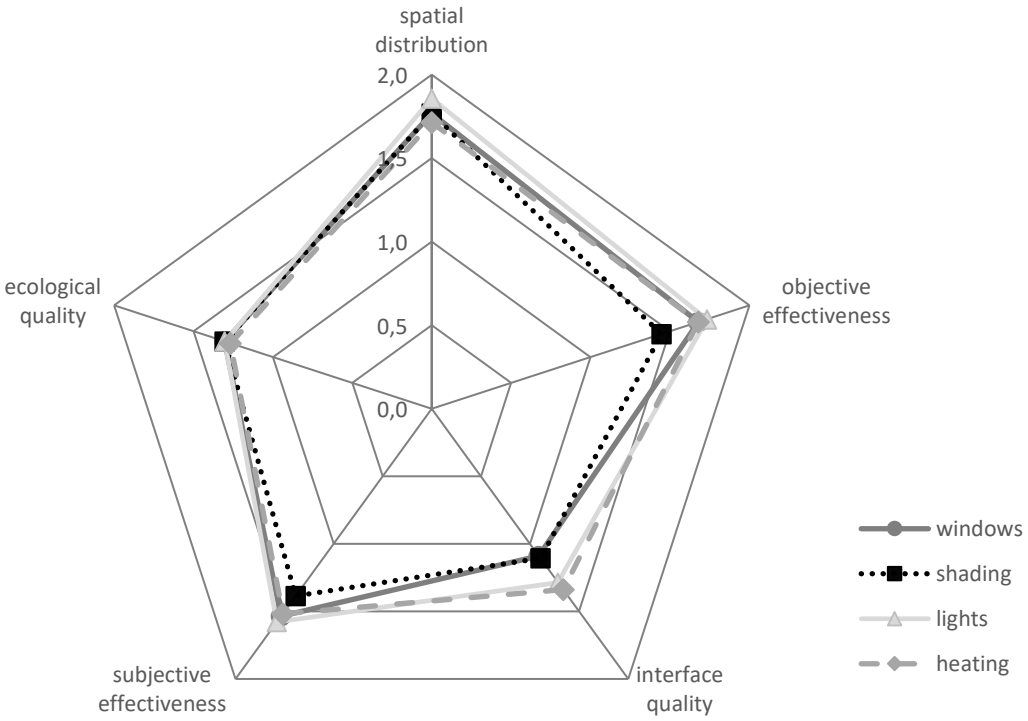

Figure 30 Results control devices office 04 (part 2)

Meeting Room:

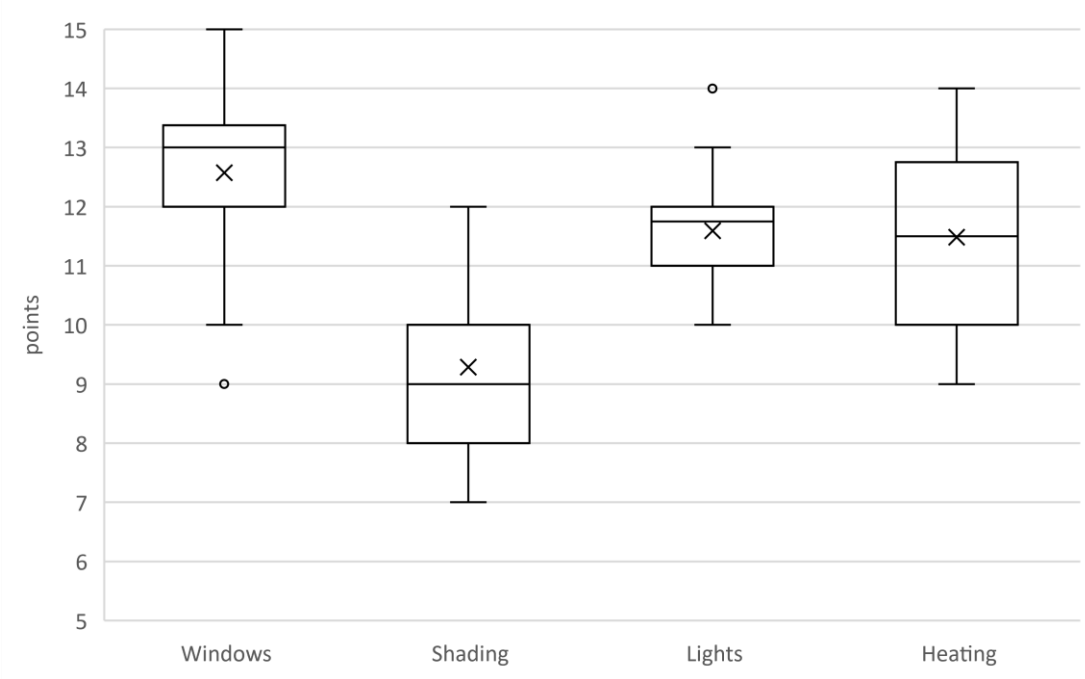

Figure 31 Boxplot: control devices meeting room (points from part 1 and part 2)

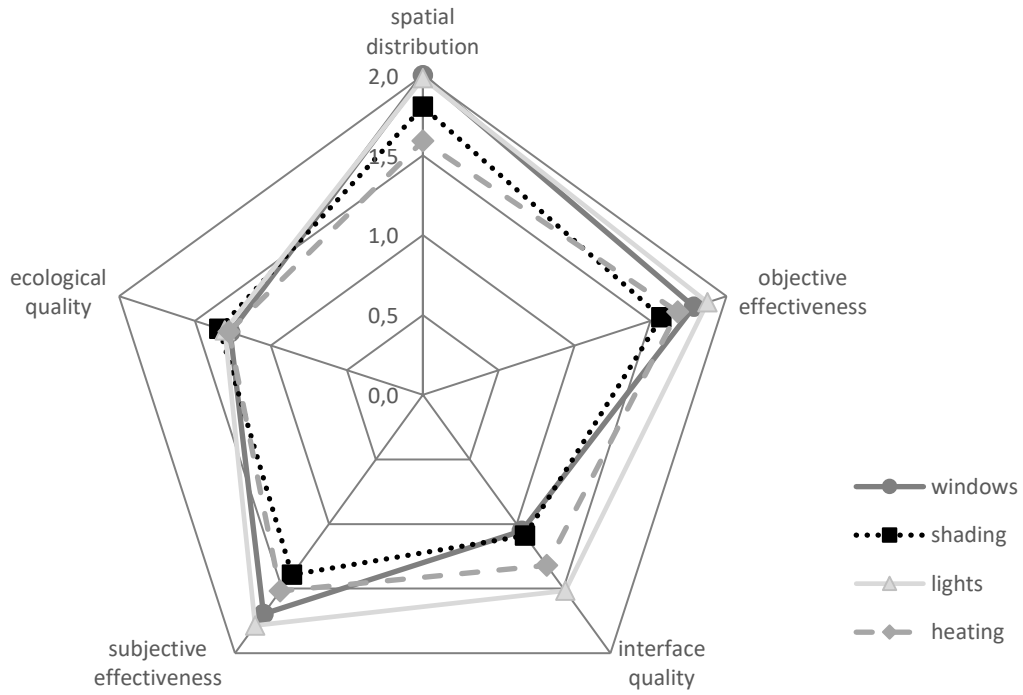

Figure 32 Results control devices meeting room (part 2)

Overall office area:

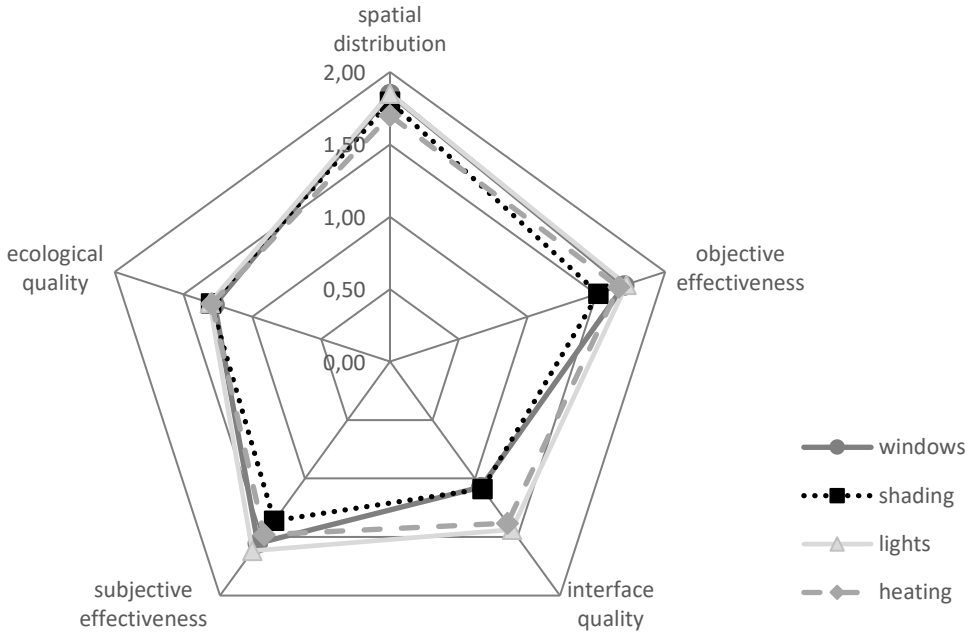

Figure 33 Results control devices overall office area (part 2)

4.2.5 Room-wise evaluation

Figure 34 shows a boxplot containing the ecological valency index of each of the rooms as well as the overall office area. In this case the weighting factors are included.

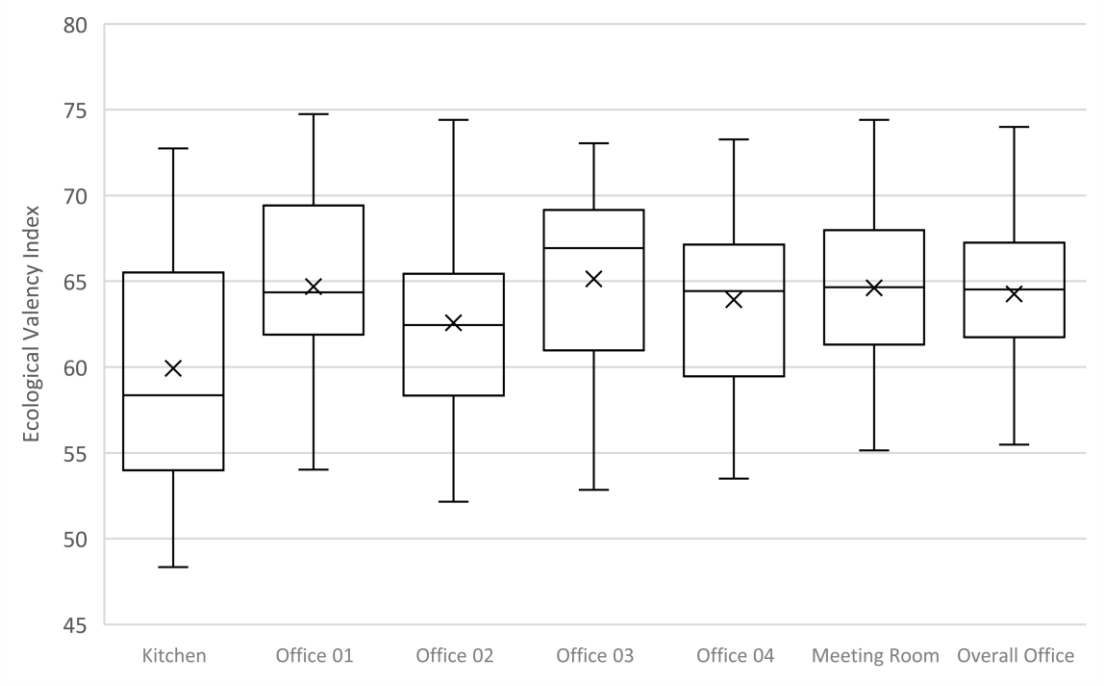

Figure 34 Boxplot: ecological valency evaluation method rooms

4.2.6 Occupants vs visitors

Figure 35 shows a comparison of the results from the occupants and the visitors.

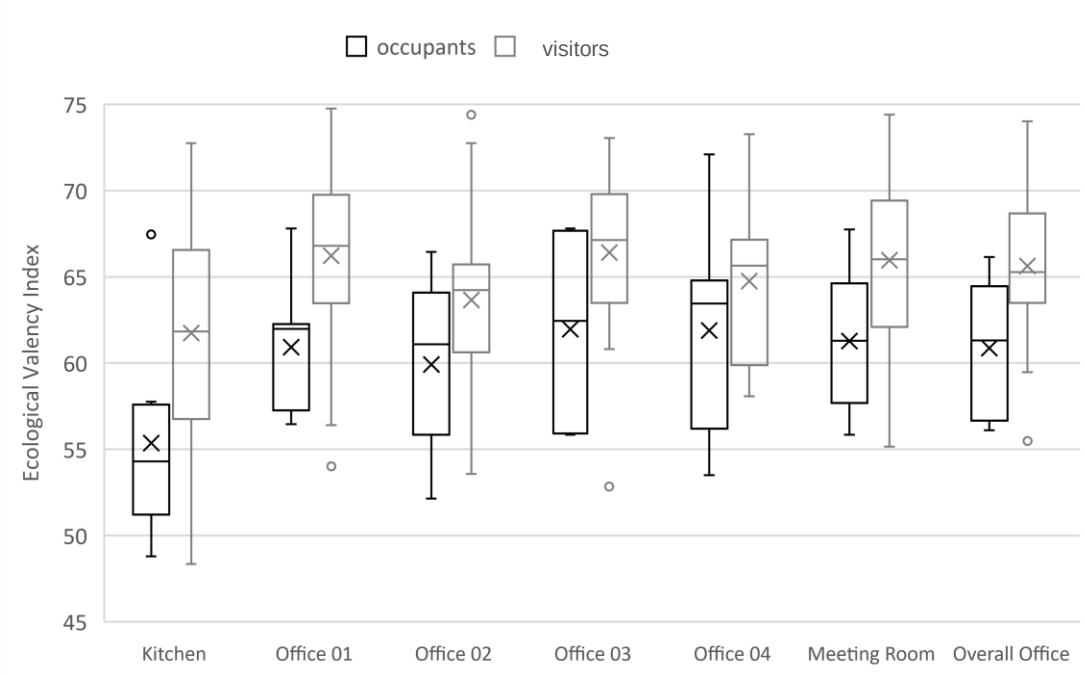

Figure 35 Boxplot: comparison of the results from the occupants and the visitors

In Figure 36 the mean results from the occupants are compared to the outcome of the visitors. This is done for each room of the office area.

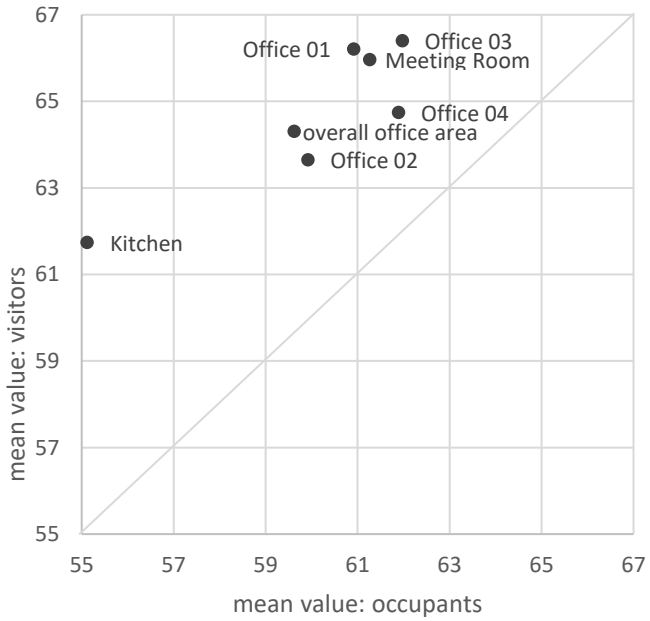

Figure 36 Comparison of the results from the occupants and the visitors

4.2.7 Female vs male

A comparison of the outcome from the female and the male participants is shown in Figure 37 and 38.

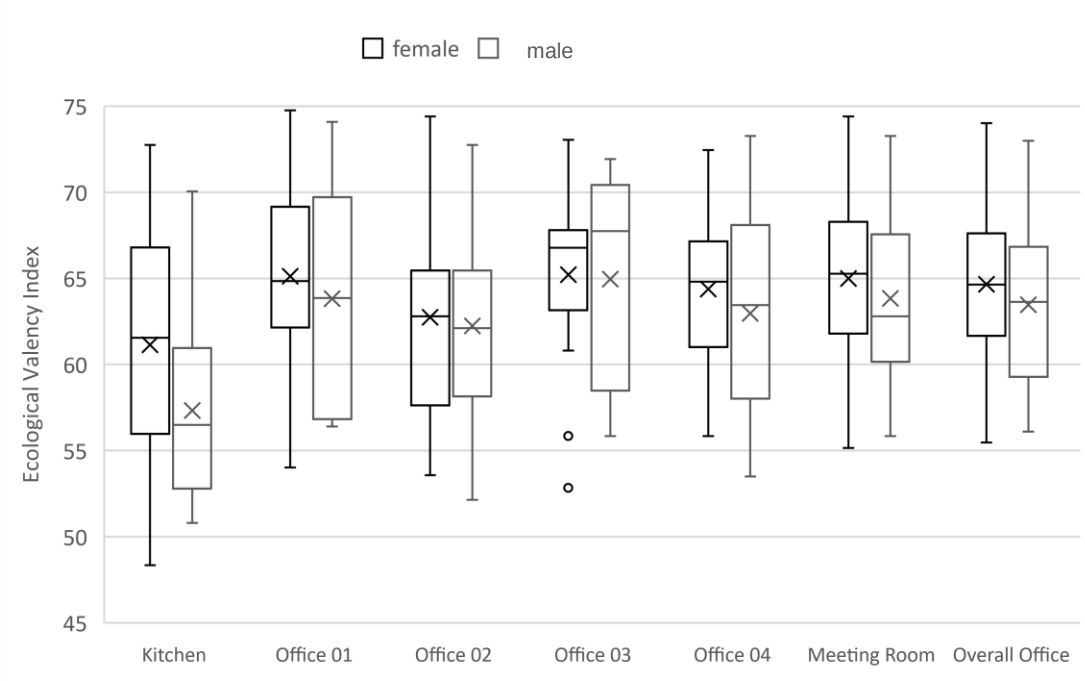

Figure 37 Boxplot: comparison results: female and male participants

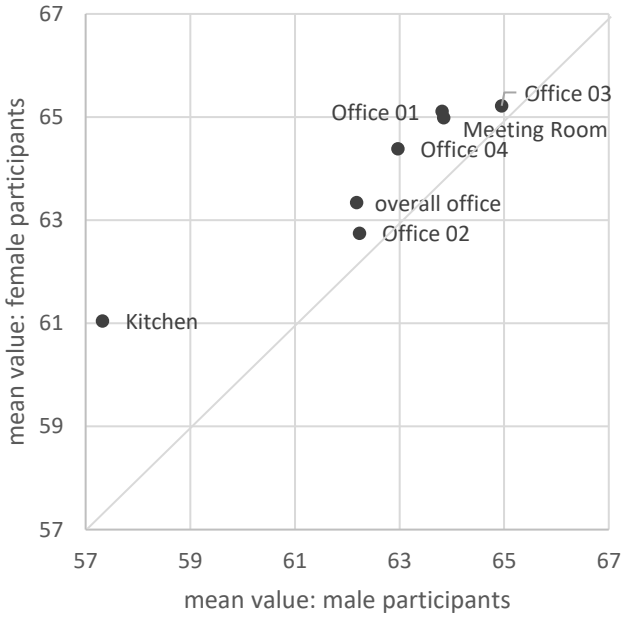

Figure 38 Comparison of the results from the female and the male participants

4.2.8 Feedback from the participants

Figure 39 and 40 show the outcome of the feedback questions. While Figure 39 deals with the understandability of the evaluation method, Figure 40 looks at the usability.

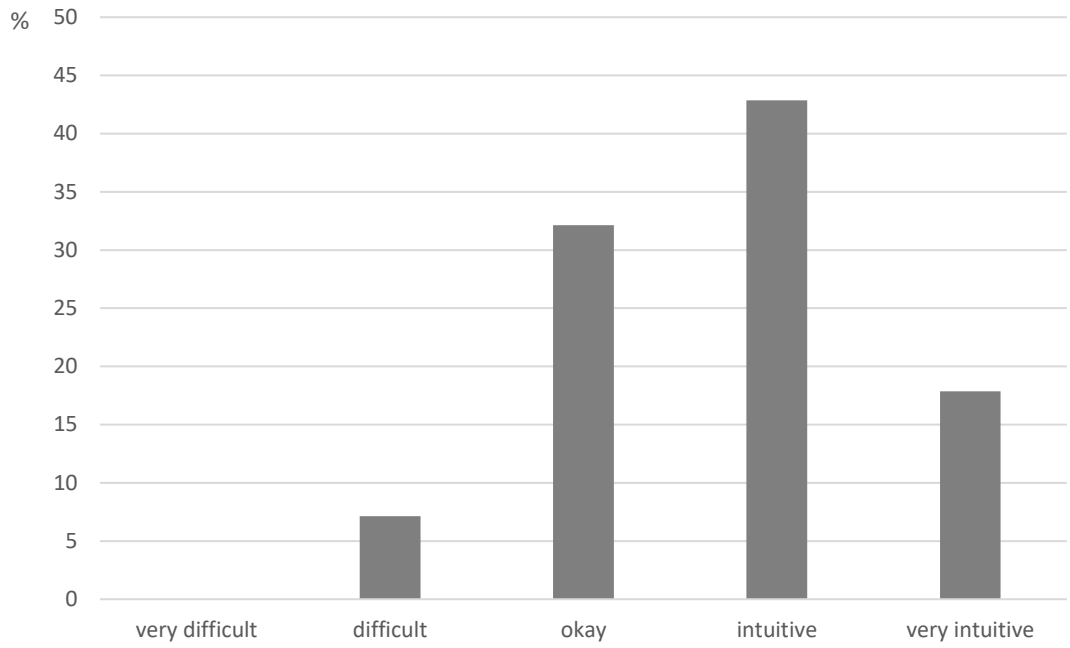

Figure 39 Feedback participants - understandability of the evaluation method

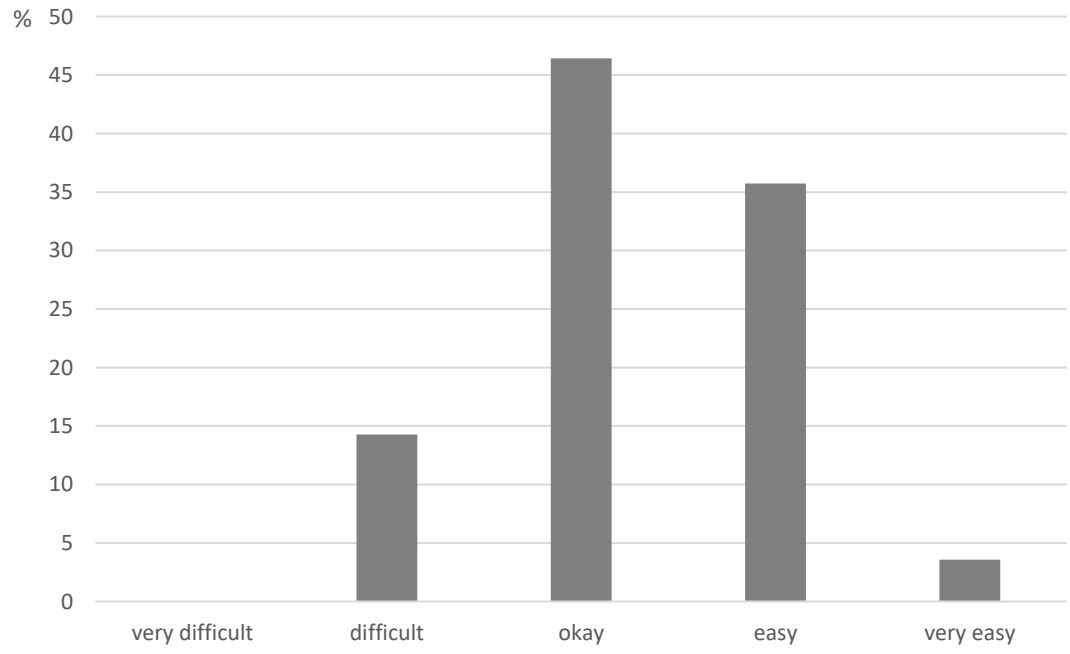

Figure 40 Feedback participants - choosing points for the categories

All in all, fourteen of the participants gave additional feedback. Some of their comments are included below. Three of them (Participant 1, 11 and 19) suggested that the rooms, which were chosen for the experiment could have been more different:

“Rooms of department are very similar, which may reduce the difference between EVI points” (Participant 1)

“Due to similar structures and equipment of the office many fields could be filled similarly.” (Participant 11)

Four participants (Participant 1, 9, 12, and 15) addressed that adding more categories or giving more options for choosing points could improve the evaluation method.

“The number of points, or the difference between choices need to be finer” (Participant 1)

“Maybe would be good to add more assessment categories for shading and heating as it was not that clear how to describe situations when blinders are “in the middle of the window”.” (Participant 9)

Participant 9 and 15 stated that in their opinion a category dealing with acoustics would be a good addition.

“Due to construction work and permanent noise it would be good to include noise into assessment.” (Participant 9)

Participant 12 suggests to use the category cooling only in specific circumstances.

“I would also recommend to examine the interior air temperature and if, and only if it reaches a certain value during summer then consider the cooling system, because in a room where there is no necessity to install a cooling system, the point system should not include it, because it makes it less efficient in the point system.” (Participant 12)

4.3 Discussion

In this chapter, the results of the case study are discussed. This is done with regards to the initial research questions, presented in chapter 4.1.4.

Q1 How did the participants evaluate part one?

Table 9 shows to which degree participants' results of the first part diverge. This is illustrated in form of the coefficient of variation. It is noticeable that these values are between 6.11 and 29.99 percent. This is dependent on the kind of evaluated control device and on the room. In Figure 41 the distribution of the resulting coefficient of variation values is illustrated. It includes the values from part one. To compare, the coefficient of variation results from part two can be found as well. Regarding part one, the mean coefficient of variation value is 12.68 percent. Furthermore, it can be seen that the highest value of 29.99 percent is an outlier.

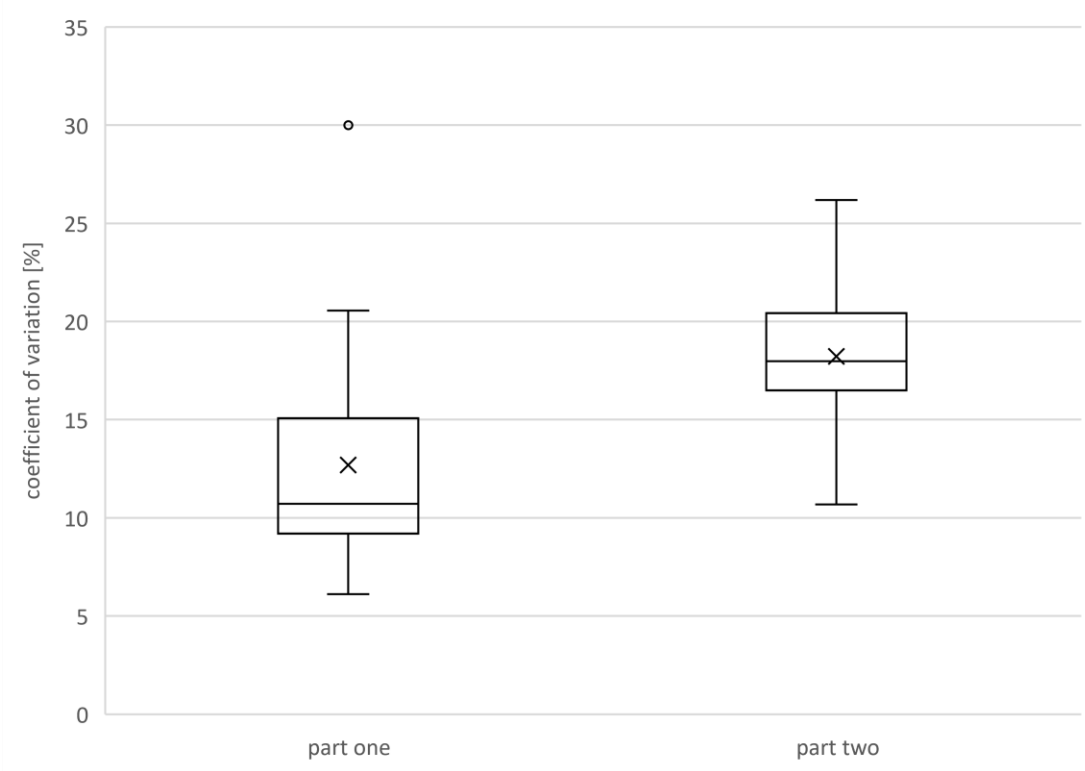

Figure 41 Coefficient of variation: evaluation of part one and part two

Table 9 and Figure 41 show that the results of part one generally match with the previously stated hypothesis (chapter 4.1.4), because the participants answered rather similar. However, it is noticeable that some categories feature higher differences of participants' results. The highest ones can be found in the category

shading, especially in Office 01. A reason for these differences can be the position of the blinds. In all rooms of the office area, the shading system is located between the two glass layers of the window (between the interior and exterior casement). The results (Annex 8.2) show that all of the participants have noticed it as an interior shading system. However, some of them decided give additional points for the category exterior shading as well. In Office 01 two windows offer additional blinds in front of the window on the interior side of the room. These two aspects could be the reason for the different results.

Therefore, there is still some room for improvement. A possible solution may be a more detailed point system in some categories.

Q2 How did the participants evaluate part two?

Table 10 and Figure 41 show that part two of the evaluation method features a higher variation of participants' results. This is noticeable especially in comparison to the outcome of part one. While the mean coefficient of variation value of part two is 18.22 percent, it is 12.68 percent for part one. The highest variation of part two can be found in the category lights. For the evaluation of the kitchen lights the coefficient of variation is 26.18 percent. However, the category in which the participants agreed the most is lights as well. For Office 03 and the Meeting Room the answers of the participants regarding luminaires are rather similar. The lights of Office 03 and the Meeting Room are also the two categories that received the highest amount of points of part two.

Also, in this case the stated hypothesis matches the result. As predicted, the variation of points is higher for part two than for part one. It shows that evaluating the devices for their spatial distribution, ecological quality, effectiveness (objective and subjective) and interface quality is more subjective. Finer differences of choices and points could be a possibility to improve the method.

Q3 Are there system related differences?

Figure 21 – 33 shows the outcome of each control equipment. The results show that the shading devices received less points than the other control devices and elements.

Figure 33 deals with the overall office area. It illustrates the points each device received on average for the evaluation criteria of part two. It is noticeable that the

devices got a very similar amount of points for their ecological quality. Also for the spatial distribution the equipment was rated rather similar. Differences can be found for the interface quality. Here, the windows and shading systems received lower results. The interface quality of the heating systems and luminaires was perceived better.

Furthermore, there are three cases where all of the participants agreed on the performance of a control device in part two. Every participant gave two points for the spatial distribution of the windows of Office 01, Office 03 and the Meeting Room.

Q4 Are there room related differences?

Figure 34 illustrates the results of each room in the office area. It is noticeable that the rooms were evaluated rather similarly by the participants. The average Ecological Valency Index lies for each room between 62.6 and 66.9. The only exception is the kitchen. Here, the Ecological Valency Index is slightly lower. The mean value is 58.4. A reason for these similar results can be the fact that the evaluated rooms are often equipped similarly. For example, each room, except for the kitchen offers the same window type. However, regarding the luminaires of the space, different types and arraignments can be found.

Q5 Are there differences between the results of the occupants compared to the visitors?

It is shown in Figure 35 and 36 that the results of the occupants and the visitors diverge. It noticeable that the occupants gave clearly less points for all of the rooms, even though they assessed the same spaces as the visitors. A possibility is that the occupants have a better knowledge about the space. They have already used the devices and presumably know aspects about their performance and therefore evaluated the rooms in a different way.

Nevertheless, it has to be mentioned that the number of occupants evaluating the space was not equal to the number of visitors. While twenty visitors participated, eight occupants did the assessment. This has also an influence on the comparability of the result.

Q6 Are there differences between the results of the female participants compared to the male participants?

Figure 37 as well as Figure 38 compare of the outcome of the women and the men. In this case it should also be stated that for this comparison the number of female participants was not equal to the number of male participants. While nineteen women participates, nine men took part in this experiment.

The results show that the female participants rated the rooms slightly better than the male participants. Nevertheless, it is noticeable that the differences are rather small, especially by looking at the mean values. The difference in the evaluation of the kitchen space is noteworthy, but should not be overstated here due to the small number of evaluators.

Q7 What is the feedback from the participants?

Figure 39 illustrates that 17.9 percent of the participants consider the evaluation method as very intuitive. With 42.9 percent the answering option “intuitive” was selected from the most participants. While 32.1 percent thought that the understandability of protocol is okay, 7.1 percent said that it was difficult. No participant stated that the protocol was very difficult to understand. Nevertheless, there is still room for improvement.

Choosing points for the categories was difficult for 14.3 percent of the participants. This is shown in Figure 40. While 46.4 percent stated it was okay, 35.7 percent thought it was easy. Only 3.6 percent said that deciding for which points to choose was very easy. Out of the five possible answering options, no participant stated that this was a very difficult task. However, the most chosen answering option was “okay”. Therefore, the point system can still be improved to make it easier and more intuitive. Finer differences between the choices could be a solution for that issue.

5 CONCLUSION

5.1 Summary of the contents

This master thesis deals with the potentials and challenges of an buildings-oriented ecological valency evaluation method. For this purpose, a specific attempt was presented to develop a general structure for such a method. The method and the respective procedures is intended to facilitate the evaluation of multiple environmental control devices and equipment in architectural spaces.

Devices are evaluated in two distinct steps. The first step focuses on the availability of the control equipment and their key attributes. Depending on the provided device functionalities, quality points are awarded. The second step deals with the quality and performance of the control equipment. To this end, devices are evaluated in five categories, initially introduced in previous publications (Mahdavi 2018, Mahdavi and Berger 2019). These are spatial distribution, objective effectiveness, interface quality, subjective effectiveness and ecological quality. The proposed method includes also procedural steps for assigning weights to different devices. Likewise, guiding is provided as to how to derive an overall ecological valency index for a building based on integration of the respective values of individual spaces.

The proposed structure and the derivative protocol was tested using the case of an office area in an educational building in Vienna, Austria. Twenty-eight people participated in this experiment and assessed individually six different rooms within this office area.

The results of this test show that – as plausibly predicted – participants answered rather similarly with regard to the protocol's (availability-oriented) first part. Regarding the second step in the protocol, the variation of allocated points by participants was found to be significantly larger. Therefore, it can be assumed that evaluation the quality or performance of a device is a more subjective process. To address this issue, a more pronounced differentiation in terms of the underlying evaluation points system may be beneficial.

Furthermore, the results reveal a fairly consistent evaluation of all the rooms of the office area. This circumstance can be explained if it is considered that the assessed rooms are in most cases similarly equipped.

Comparison of the evaluations made by the occupants to those by visitors reveal noticeable differences. Generally speaking, as compared to occupants, visitor

evaluated the rooms more favorably. However, no significant difference could be found between the outcomes of the evaluations made by female versus male participants.

The feedback from the participants regarding the usability of the method suggests that only seven percent found it difficult to apply the protocol (the rest found it either acceptable, intuitive, or very intuitive). The participants were also asked to express their opinion regarding the challenge of assigning points to device attributes. Only 14 percent of the participants found selection of the proper points difficult. The rest found either acceptable, easy, or very easy.

5.2 Future research

In future, the proposed ecological valency evaluation method for buildings should be tested with a higher number of participants and a larger sample of rooms and buildings. Thus, a variety of devices, control systems, room functions, and building types could be considered, leading to a more robust and representative method examination. Moreover, consideration of different contextual (e.g., urban versus suburban) and climatic conditions could provide further insights into the coverage and robustness of the evaluation method and procedure.

Furthermore, the potential for improving and optimizing the presented evaluation could be further exploited. As an example, protocol versions with additional/different categories or with a finer point systems could be developed and tested. Another inquiry could address the relative importance assigned to the quality of the devices versus their availability.

Last but not least, alternatives to a purely numeric evaluation method of buildings' ecological valency could be searched for. Ultimately, the experience gained from the exercise presented in thesis suggests that, independent of their immediate potential for realization, efforts in definition and analysis of buildings' ecological valency can contribute to the increased sensitivity of building designers, operators, and occupants with regard to the indoor environmental quality and controllability and the associated implications for people's health, comfort, and productivity.

6 INDEX

6.1 List of Figures

6.2 List of Tables

6.3 List of Equations

7 LITERATURE

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8 APPENDIX

8.1 Evaluation protocol of the case study

The following figures show the evaluation protocol. The participants of the case study received this protocol to assess the office area.

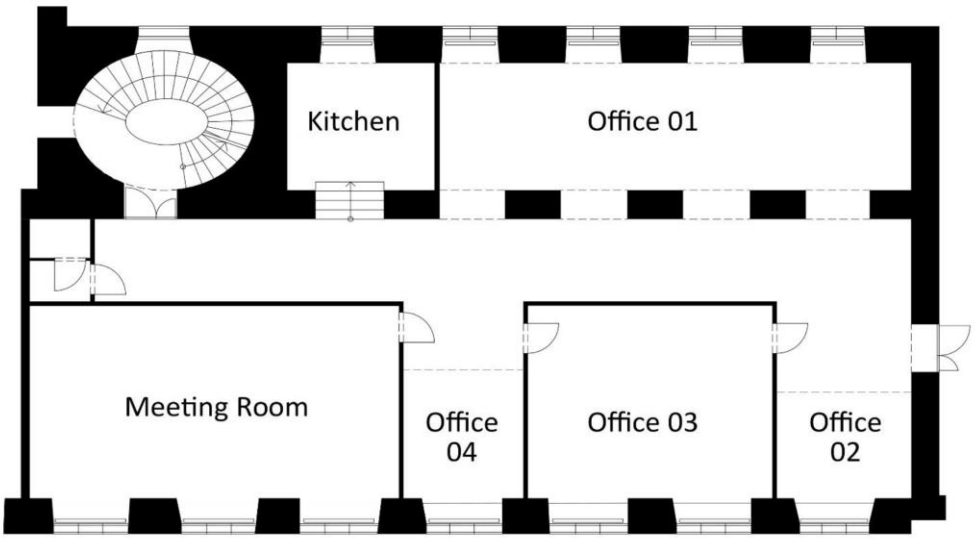
Department assessment

Name:

Student ID:

Gender: □ female □ male

Age: □ 18-20 □ 21-23 □ 24-26 □ 27-29 □ >30



Rooms	Area [m²]	Number of people	weight (w) *	Points (EVI)	EVI × w
Kitchen	12.8	2	0.07		
Office 01	46.6	7	0.27		
Office 02	9.2	1	0.05		
Office 03	36.5	1	0.19		
Office 04	11.5	1	0.06		
Meeting Room	56.1	20	0.36		
∑	172.7	32	1		

* $\frac{A}{\sum A} \times 0.9 + \frac{n}{\sum n} \times 0.1$

Room: Kitchen | Number of people: 2 | Area [m²]: 12.8

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

Room EVI	

Room: Office 01 | Number of people: 7 | Area [m²]: 46.6

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

Room EVI	

Room: Office 02 | Number of people: 1 | Area [m²]: 9.2

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

Room EVI	

Room: Office 03 | Number of people: 1 | Area [m²]: 36.5

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

Room EVI	

Room: Office 04 | Number of people: 1 | Area [m²]: 11.5

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

Room EVI	

Room: Meeting Room | Number of people: 20 | Area [m²]: 56.1

windows

	max. points	points
no	0	
yes	2	
turn function	2	
tilt function	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

shading

	max. points	points
no	0	
interior shading	2	
exterior shading	3	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1
X	

lights

	max. points	points
no	0	
ambient	2	
task	1	
dimming	1	
on/off	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.35

heating

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

points part 1 + part 2	∑ x 1.65

cooling

	max. points	points
no	0	
yes	2	
radiant	2	
convective	1	
∑ part 1	5	

	0: poor 1: okay 2: good
spatial distribution	
objective effectiveness	
interface quality	
subjective effectiveness	
ecological quality	
∑ part 2	

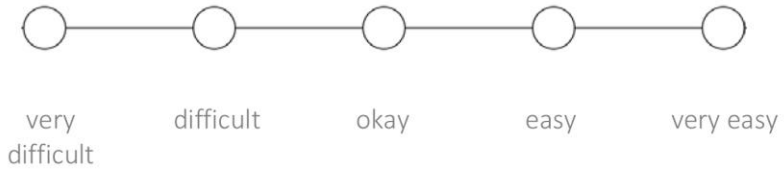
points part 1 + part 2	∑ x 1
X	

Room EVI	

Please answer the following questions:

How understandable is the protocol?

Choosing points for the different categories was...



Comments/Feedback:

8.2 Outcome of the case study

In this section the evaluation of the office area is presented for some exemplary rooms. They are the Office 01, Office 04 and the Meeting Room.

Office 01:

participants	ID-Nr.	1	2	3	4	5	6	7	8	9	10
	male/female [m; f]	m	f	m	m	f	f	m	m	f	m
	age	>30	27-29	>30	>30	24-26	24-26	27-29	>30	>30	24-26
	visitor/occupant [v; o]	o	o	o	o	o	o	v	v	v	v

windows	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2	2	2
	tilt function	1	0	1	1	1	0	1	1	1	1
	∑ part 1	5	4	5	5	5	4	5	5	5	5
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	1	2	2	2	1	2	2	2
	interface quality	1	1	0	1	1	1	1	1	1	1.5
	subjective effectiveness	1	2	1	2	1	2	1	2	1	2
	ecological quality	1	2	0	1	1	1	1	1	1	2
	∑ part 2	7	9	4	8	7	8	6	8	7	9.5
	points part 1 + part 2	12	13	9	13	12	12	11	13	12	14.5
	∑ x 1.65	19.8	21.45	14.85	21.45	19.8	19.8	18.15	21.45	19.8	23.92

shading	no	0	0	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2	2	2
	exterior shading	0	0	0	0	0	0	0	0	0	3
	∑ part 1	2	2	2	2	2	2	2	2	2	5
	spatial distribution	2	1	2	2	1	2	2	2	2	2
	objective effectiveness	1	1	1	1	1	1	2	2	1	2
	interface quality	1	1	1	1	0.5	1	1	1	1	1
	subjective effectiveness	1	2	1	0	1	2	1	2	1	2
	ecological quality	1	1	1	0	1	1	2	2	1	1
	∑ part 2	6	6	6	4	4.5	7	8	9	6	8
	points part 1 + part 2	8	8	8	6	6.5	9	10	11	8	13

	ID-Nr.	1	2	3	4	5	6	7	8	9	10
lights	no	0	0	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2	2	2
	task		1	1	1	1	1	1	1	1	1
	dimming	0	0	0	0	0	0	1	1	0	0
	on/off	1	1	1	1	1	1	1	1	1	1
	∑ part 1	3	4	4	4	4	4	5	5	4	4
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	1	1	2	2	2	2	2	2	2	2
	interface quality	1	2	1	1	1	1	1	1	2	1
	subjective effectiveness	1	2	2	2	2	2	2	2	1	2
	ecological quality	1	1	1	1	1	2	1	1	1	1
	∑ part 2	6	8	8	8	8	9	8	8	8	8
	points part 1 + part 2	9	12	12	12	12	13	13	13	12	12
	∑ x 1.35	12.15	16.2	16.2	16.2	16.2	17.55	17.55	17.55	16.2	16.2

heating	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2	2	2
	convective	0	0	0	0	0	0	0	0	0	0
	∑ part 1	4	4	4	4	4	4	4	4	4	4
	spatial distribution	2	1	2	2	2	2	2	2	2	1
	objective effectiveness	1	1	2	2	2	2	1	2	1	2
	interface quality	1	2	1	1	1	2	2	1	1	1
	subjective effectiveness	1	1	1	1	2	2	1	1	1	1
	ecological quality	1	1	1	1	1	1	1	2	1	1
	∑ part 2	6	6	7	7	8	9	7	8	6	6
	points part 1 + part 2	10	10	11	11	12	13	11	12	10	10
	∑ x 1.65	16.5	16.5	18.15	18.15	19.8	21.45	18.15	19.8	16.5	16.5

	Room EVI	56.45	62.15	57.2	61.8	62.3	67.8	63.85	69.8	60.5	69.62

participants	ID-Nr.	11	12	13	14	15	16	17	18	19	20
	male/female [m; f]	f	m	f	f	f	f	m	f	f	m
	age	21-23	21-23	27-29	21-23	27-29	24-26	27-29	21-23	24-26	27-29
	visitor/occupant [v; o]	v	v	v	v	v	v	v	v	v	v

windows	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2	2	2
	tilt function	1	1	0	0	0	1	0.5	1	0	0
	∑ part 1	5	5	4	4	4	5	4.5	5	4	4
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	2	2	2	2	2	1	2
	interface quality	1	1	1	1	1	1	2	1	1	1
	subjective effectiveness	2	1	2	2	2	2	2	2	0.5	2
	ecological quality	1	1	2	1	2	2	2	1	1	1
	∑ part 2	8	7	9	8	9	9	10	8	5.5	8
	points part 1 + part 2	13	12	13	12	13	14	14.5	13	9.5	12
	∑ x 1.65	21.45	19.8	21.45	19.8	21.45	23.1	23.925	21.45	15.675	19.8

shading	no	0	0	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2	2	2
	exterior shading	2	1	0	0	0	0	0.5	0	0	0
	∑ part 1	4	3	2	2	2	2	2.5	2	2	2
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	1	2	2	2	2	1	2	1	1
	interface quality	1	1	1	1	1	1	1	2	1	1
	subjective effectiveness	1	1	2	2	1	2	1	1	1	1
	ecological quality	1	1	1	2	2	2	2	2	1	1
	∑ part 2	7	6	8	9	8	9	7	9	6	6
	points part 1 + part 2	11	9	10	11	10	11	9.5	11	8	8

	ID-Nr.	11	12	13	14	15	16	17	18	19	20
lights	no	0	0	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2	2	2
	task	1	1	1	1	1	1		1	1	1
	dimming	0	0	0	0	0	0	0	0	0	0
	on/off	1	0	1	1	1	1	1	1	1	1
	∑ part 1	4	3	4	4	4	4	3	4	4	4
	spatial distribution	2	1	2	2	1.5	2	2	2	2	2
	objective effectiveness	2	1	1.5	2	1.5	2	2	2	1.5	2
	interface quality	2		2	1	1	1	2	2	1	2
	subjective effectiveness	2	1	1	2	1.5	2	2	2	1	2
	ecological quality	2	1	1	2	1	2	2	2	1	1
	∑ part 2	10	4	7.5	9	6.5	9	10	10	6.5	9
	points part 1 + part 2	14	7	11.5	13	10.5	13	13	14	10.5	13
	∑ x 1.35	18.9	9.45	15.525	17.55	14.175	17.55	17.55	18.9	14.175	17.55

heating	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2	2	2
	convective	1	1	0.5	0	0	0	0	1	0	0
	∑ part 1	5	5	4.5	4	4	4	4	5	4	4
	spatial distribution	2	1	2	2	2	2	2	2	2	2
	objective effectiveness	1	1	2	2	2	2	2	2	1	2
	interface quality	1	1	2	1	1	2	2	1	1	1
	subjective effectiveness	1	2	1	1	2	2	2	1	0.8	1
	ecological quality	1	1	1	1	2	2	2	1	1	2
	∑ part 2	6	6	8	7	9	10	10	7	5.8	8
	points part 1 + part 2	11	11	12.5	11	13	14	14	12	9.8	12
	∑ x 1.65	18.15	18.15	20.625	18.15	21.45	23.1	23.1	19.8	16.17	19.8

	Room EVI	69.5	56.4	67.6	66.5	67.075	74.75	74.075	71.15	54.02	65.15

participants	ID-Nr.	21	22	23	24	25	26	27	28
	male/female [m; f]	f	f	f	f	f	f	f	f
	age	24-26	21-23	21-23	27-29	24-26	24-26	24-26	27-29
	visitor/occupant [v; o]	v	v	v	v	v	v	o	o

windows	no	0	0	0	0	0	0	0	0
	yes	2	2	2	2	1	2	2	2
	turn function	2	2	2	2	2	2	2	2
	tilt function	0	0	0	0	0	1	1	0
	∑ part 1	4	4	4	4	3	5	5	4
	spatial distribution	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	1.5	2	2	2	2
	interface quality	1	1	1	0.5	0.5	2	1	2
	subjective effectiveness	2	1	2	1.5	2	2	2	1
	ecological quality	1	2	1	1	1	1	1	2
	∑ part 2	8	8	8	6.5	7.5	9	8	9
	points part 1 + part 2	12	12	12	10.5	10.5	14	13	13
	∑ x 1.65	19.8	19.8	19.8	17.325	17.325	23.1	21.45	21.45

shading	no	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2
	exterior shading	0	0	0	0	0.5	0	0	0
	∑ part 1	2	2	2	2	2.5	2	2	2
	spatial distribution	2	2	1	1.5	2	2	2	1
	objective effectiveness	1	2	2	2	1.5	1	1	0
	interface quality	1	1	2	1	1	2	1	0
	subjective effectiveness	1	1	2	1.5	1.5	1	1	2
	ecological quality	1	2	2	1	1.5	1	1	1
	∑ part 2	6	8	9	7	7.5	7	6	4
	points part 1 + part 2	8	10	11	9	10	9	8	6

	ID-Nr.	21	22	23	24	25	26	27	28
lights	no	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2
	task	1	1	1	1	1	1	1	1
	dimming	0	0	0	0	0	0	0	0
	on/off	1	1	0	1	1	1	1	0
	∑ part 1	4	4	3	4	4	4	4	3
	spatial distribution	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	1.5	1.5	2	2	1
	interface quality	2	1	2	1	1	2	1	1
	subjective effectiveness	2	2	2	1.5	1	2	2	1
	ecological quality	1	2	2	1	1.5	2	1	2
	∑ part 2	9	9	10	7	7	10	8	7
	points part 1 + part 2	13	13	13	11	11	14	12	10
	∑ x 1.35	17.55	17.55	17.55	14.85	14.85	18.9	16.2	13.5

heating	no	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2
	convective	0	0	0	1	1	0	0	0
	∑ part 1	4	4	4	5	5	4	4	4
	spatial distribution	2	2	1	2	1.5	1	1	1
	objective effectiveness	2	2	2	2	1.5	1	1	1
	interface quality	1	2	1	1	2	2	2	1
	subjective effectiveness	1	2	1	2	1.5	1	1	1
	ecological quality	1	2	1	1.5	1	2	1	2
	∑ part 2	7	10	6	8.5	7.5	7	6	6
	points part 1 + part 2	11	14	10	13.5	12.5	11	10	10
	∑ x 1.65	18.15	23.1	16.5	22.275	20.625	18.15	16.5	16.5

	Room EVI	63.5	70.45	64.85	63.45	62.8	69.15	62.15	57.45

Office 04:

participants	ID-Nr.	1	2	3	4	5	6	7	8	9	10
	male/female [m; f]	m	f	m	m	f	f	m	m	f	m
	age	>30	27-29	>30	>30	24-26	24-26	27-29	>30	>30	24-26
	visitor/occupant [v; o]	o	o	o	o	o	o	v	v	v	v

windows	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2	2	2
	tilt function	1	0	1	1	1	0	1	1	1	1
	∑ part 1	5	4	5	5	5	4	5	5	5	5
	spatial distribution	1	2	2	1	2	2	1	2	2	2
	objective effectiveness	2	2	1	2	2	2	1	2	2	2
	interface quality	1	1	0	2	1	1	1	1	2	1
	subjective effectiveness	1	2	1	2	1	2	1	2	1	2
	ecological quality	1	2	0	1	1	1	2	2	1	2
	∑ part 2	6	9	4	8	7	8	6	9	8	9
	points part 1 + part 2	11	13	9	13	12	12	11	14	13	14
	∑ x 1.65	18.15	21.45	14.85	21.45	19.8	19.8	18.15	23.1	21.45	23.1

shading	no	0	0	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2	2	2
	exterior shading	0	0	0	0	0	0	0	0	0	0
	∑ part 1	2	2	2	2	2	2	2	2	2	2
	spatial distribution	1	1	2	1	1	2	2	2	2	2
	objective effectiveness	1	1	1	1	1	1	2	2	1	2
	interface quality	1	1	1	1	1	1	1	1	1	1
	subjective effectiveness	1	2	1	1	1	2	1	2	1	2
	ecological quality	1	1	1	1	1	1	2	2	1	1
	∑ part 2	5	6	6	5	5	7	8	9	6	8
	points part 1 + part 2	7	8	8	7	7	9	10	11	8	10

	ID-Nr.	1	2	3	4	5	6	7	8	9	10
lights	no	0	0	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2	2	2
	task	0	1	1	0	1	1	2	0	1	1
	dimming	0	0	0	0	0	0	0	0	0	0
	on/off	1	1	1	1	1	1	1	1	1	1
	∑ part 1	3	4	4	3	4	4	5	3	4	4
	spatial distribution	2	2	2	2	2	1	2	2	1	2
	objective effectiveness	2	1	2	2	2	2	1	2	2	2
	interface quality	1	1	1	1	1	1	1	1	1	1
	subjective effectiveness	1	2	2	2	2	2	1	2	1	2
	ecological quality	1	1	1	1	1	2	1	1	1	1
	∑ part 2	7	7	8	8	8	8	6	8	6	8
	points part 1 + part 2	10	11	12	11	12	12	11	11	10	12
	∑ x 1.35	13.5	14.85	16.2	14.85	16.2	16.2	14.85	14.85	13.5	16.2

heating	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2	2	2
	convective	0	0	0	0	0	0	0	0	0	0
	∑ part 1	4	4	4	4	4	4	4	4	4	4
	spatial distribution	1	2	2	2	2	2	1	1	2	2
	objective effectiveness	1	1	2	2	2	1	1	2	1	2
	interface quality	1	2	1	2	1	2	2	1	1	1
	subjective effectiveness	1	2	1	2	2	2	1	1	1	2
	ecological quality	1	1	1	1	1	1	1	2	1	1
	∑ part 2	5	8	7	9	8	8	6	7	6	8
	points part 1 + part 2	9	12	11	13	12	12	10	11	10	12
	∑ x 1.65	14.85	19.8	18.15	21.45	19.8	19.8	16.5	18.15	16.5	19.8

	Room EVI	53.5	64.1	57.2	64.75	62.8	64.8	59.5	67.1	59.45	69.1

participants	ID-Nr.	11	12	13	14	15	16	17	18	19	20
	male/female [m; f]	f	m	f	f	f	f	m	f	f	m
	age	21-23	21-23	27-29	21-23	27-29	24-26	27-29	21-23	24-26	27-29
	visitor/occupant [v; o]	v	v	v	v	v	v	v	v	v	v

windows	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2	2	2
	tilt function	1	1	0	0	0	1	0.5	1	1	1
	∑ part 1	5	5	4	4	4	5	4.5	5	5	5
	spatial distribution	1	2	1	2	2	2	2	2	2	1
	objective effectiveness	2	1	1.5	2	1	2	1	2	1.5	1
	interface quality	1	1	1	1	1	1	2	1	1	1
	subjective effectiveness	2	1	1	2	1	1	2	1	1.5	1
	ecological quality	1	1	2	1	2	2	2	1	1	1
	∑ part 2	7	6	6.5	8	7	8	9	7	7	5
	points part 1 + part 2	12	11	10.5	12	11	13	13.5	12	12	10
	∑ x 1.65	19.8	18.15	17.325	19.8	18.15	21.45	22.275	19.8	19.8	16.5

shading	no	0	0	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2	2	2
	exterior shading	1	1	0	0	0	0	0	0	0	0
	∑ part 1	3	3	2	2	2	2	2	2	2	2
	spatial distribution	2	2	2	2	2	2	2	2	2	1
	objective effectiveness	1	1	2	2	2	2	1	2	1	2
	interface quality	1	1	1	1	1	2	1	1	1	1
	subjective effectiveness	1	1	2	2	1	2	1	1	0.8	1
	ecological quality	1	1	1	2	2	2	2	2	1	1
	∑ part 2	6	6	8	9	8	10	7	8	5.8	6
	points part 1 + part 2	9	9	10	11	10	12	9	10	7.8	8

	ID-Nr.	11	12	13	14	15	16	17	18	19	20
lights	no	0	0	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2	2	2
	task	1	1	1	1	1	1	1	0	1	1
	dimming	0	0	0	0	0	0	0	0	0	0
	on/off	1	0	1	1	1	1	1	1	1	1
	∑ part 1	4	3	4	4	4	4	4	3	4	4
	spatial distribution	2	2	2	2	1	2	2	2	2	2
	objective effectiveness	2	2	2	2	0.5	2	2	2	1.5	2
	interface quality	2	1	2	1	0.5	1	2	2	1	2
	subjective effectiveness	2	2	2	1	0.5	2	2	2	1.2	1
	ecological quality	1	1	1	2	1	2	2	2	1	1
	∑ part 2	9	8	9	8	3.5	9	10	10	6.7	8
	points part 1 + part 2	13	11	13	12	7.5	13	14	13	10.7	12
	∑ x 1.35	17.55	14.85	17.55	16.2	10.125	17.55	18.9	17.55	14.445	16.2

heating	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2	2	2
	convective	1	1	0.5	0	0	0	0	1	0	0
	∑ part 1	5	5	4.5	4	4	4	4	5	4	4
	spatial distribution	2	2	2	2	2	2	2	1	2	2
	objective effectiveness	2	2	2	2	1	2	2	2	1.5	2
	interface quality	1	1	2	1	1	2	2	1	1.5	1
	subjective effectiveness	1	1	2	1	2	1	2	2	1.5	1
	ecological quality	1	2	1	1	2	2	2	1	1	1
	∑ part 2	7	8	9	7	8	9	10	7	7.5	7
	points part 1 + part 2	12	13	13.5	11	12	13	14	12	11.5	11
	∑ x 1.65	19.8	21.45	22.275	18.15	19.8	21.45	23.1	19.8	18.975	18.15

	Room EVI	66.15	63.45	67.15	65.15	58.075	72.45	73.275	67.15	61.02	58.85

participants	ID-Nr.	21	22	23	24	25	26	27	28
	male/female [m; f]	f	f	f	f	f	f	f	f
	age	24-26	21-23	21-23	27-29	24-26	24-26	24-26	27-29
	visitor/occupant [v; o]	v	v	v	v	v	v	o	o

windows	no	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2
	tilt function	1	0	0	1	1	1	1	0
	∑ part 1	5	4	4	5	5	5	5	4
	spatial distribution	2	2	2	2	1.5	2	2	2
	objective effectiveness	2	2	2	1.5	1.5	2	2	1
	interface quality	1	1	1	1	0.5	1	2	1
	subjective effectiveness	2	2	2	1.5	2	2	2	1
	ecological quality	1	2	1	1	1.5	1	1	1
	∑ part 2	8	9	8	7	7	8	9	6
	points part 1 + part 2	13	13	12	12	12	13	14	10
	∑ x 1.65	21.45	21.45	19.8	19.8	19.8	21.45	23.1	16.5

shading	no	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2
	exterior shading	0	0	0	0	0.5	0	0	0
	∑ part 1	2	2	2	2	2.5	2	2	2
	spatial distribution	2	2	1	1.5	2	2	2	2
	objective effectiveness	2	1	2	1.5	1	1	2	1
	interface quality	1	1	2	1.5	1.5	1	1	1
	subjective effectiveness	1	2	2	1.5	1.5	1	2	1
	ecological quality	1	2	2	0.5	1	1	1	1
	∑ part 2	7	8	9	6.5	7	6	8	6
	points part 1 + part 2	9	10	11	8.5	9.5	8	10	8

	ID-Nr.	21	22	23	24	25	26	27	28
lights	no	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2
	task	1	1	1	0	1	1	1	1
	dimming	0	0	0	0	0	0	0	0
	on/off	1	0	1	1	1	1	1	1
	∑ part 1	4	3	4	3	4	4	4	4
	spatial distribution	2	2	2	2	2	1	2	2
	objective effectiveness	2	2	1	2	1.5	1	2	1
	interface quality	1	1	2	1	1.5	2	2	1
	subjective effectiveness	2	2	1	1.5	1	1	2	1
	ecological quality	1	2	1	1	1.5	2	1	2
	∑ part 2	8	9	7	7.5	7.5	7	9	7
	points part 1 + part 2	12	12	11	10.5	11.5	11	13	11
	∑ x 1.35	16.2	16.2	14.85	14.175	15.525	14.85	17.55	14.85
heating	no	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2
	convective	0	0	0	1	1	0	0	0
	∑ part 1	4	4	4	5	5	4	4	4
	spatial distribution	2	2	1	1.5	1.5	1	2	1
	objective effectiveness	2	2	2	2	1.5	1	2	1
	interface quality	1	1	1	1	2	1	2	1
	subjective effectiveness	2	2	1	2	2	1	2	1
	ecological quality	1	2	1	1.5	1	1	1	2
	∑ part 2	8	9	6	8	8	5	9	6
	points part 1 + part 2	12	13	10	13	13	9	13	10
	∑ x 1.65	19.8	21.45	16.5	21.45	21.45	14.85	21.45	16.5
	Room EVI	66.45	69.1	62.15	63.925	66.275	59.15	72.1	55.85

Meeting Room:

participants	ID-Nr.	1	2	3	4	5	6	7	8	9	10
	male/female [m; f]	m	f	m	m	f	f	m	m	f	m
	age	>30	27-29	>30	>30	24-26	24-26	27-29	>30	>30	24-26
	visitor/occupant [v; o]	o	o	o	o	o	o	v	v	v	v

windows	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2	2	2
	tilt function	1	0	1	1	1	0	1	1	1	1
	∑ part 1	5	4	5	5	5	4	5	5	5	5
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	1	2	2	1	2	2	2	2
	interface quality	1	1	0	1	1	1	1	1	1	2
	subjective effectiveness	1	2	1	2	1	2	2	2	1	2
	ecological quality	1	2	0	1	1	1	1	1	1	2
	∑ part 2	7	9	4	8	7	7	8	8	7	10
	points part 1 + part 2	12	13	9	13	12	11	13	13	12	15
	∑ x 1.65	19.8	21.45	14.85	21.45	19.8	18.15	21.45	21.45	19.8	24.75

shading	no	0	0	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2	2	2
	exterior shading	0	0	0	0	0	0	0	0	0	0
	∑ part 1	2	2	2	2	2	2	2	2	2	2
	spatial distribution	2	1	2	2	1	2	2	2	1	2
	objective effectiveness	1	1	1	1	1	1	2	2	1	2
	interface quality	1	1	1	1	1	1	1	1	1	1
	subjective effectiveness	1	2	1	1	1	2	1	1	1	2
	ecological quality	1	1	1	1	1	1	2	2	1	1
	∑ part 2	6	6	6	6	5	7	8	8	5	8
	points part 1 + part 2	8	8	8	8	7	9	10	10	7	10

	ID-Nr.	1	2	3	4	5	6	7	8	9	10
lights	no	0	0	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2	2	2
	task	0	0	0	0	0	0	0	0	1	0.5
	dimming	0	0	0	0	0	0	0	0	0	0
	on/off	1	1	1	1	1	0	1	1	1	1
	∑ part 1	3	3	3	3	3	2	3	3	4	3.5
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	2	2	2	2	2	1	2
	interface quality	1	2	1	1	1.5	1	1	1	1	1
	subjective effectiveness	2	2	2	2	1	2	2	2	1	1
	ecological quality	1	1	1	2	1	2	1	1	1	1
	∑ part 2	8	9	8	9	7.5	9	8	8	6	7
	points part 1 + part 2	11	12	11	12	10.5	11	11	11	10	10.5
	∑ x 1.35	14.85	16.2	14.85	16.2	14.175	14.85	14.85	14.85	13.5	14.175

heating	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2	2	2
	convective	0	0	0	0	0	0	0	0	0	0
	∑ part 1	4	4	4	4	4	4	4	4	4	4
	spatial distribution	2	1	2	2	2	1	1	1	1	2
	objective effectiveness	1	1	2	2	2	2	1	1	1	2
	interface quality	1	2	1	1	1	2	2	1	1	1
	subjective effectiveness	1	1	1	2	2	2	1	1	1	1
	ecological quality	1	1	1	1	1	1	1	1	1	1
	∑ part 2	6	6	7	8	8	8	6	5	5	7
	points part 1 + part 2	10	10	11	12	12	12	10	9	9	11
	∑ x 1.65	16.5	16.5	18.15	19.8	19.8	19.8	16.5	14.85	14.85	18.15

	Room EVI	59.15	62.15	55.85	65.45	60.775	61.8	62.8	61.15	55.15	67.075

participants	ID-Nr.	11	12	13	14	15	16	17	18	19	20
	male/female [m; f]	f	m	f	f	f	f	m	f	f	m
	age	21-23	21-23	27-29	21-23	27-29	24-26	27-29	21-23	24-26	27-29
	visitor/occupant [v; o]	v	v	v	v	v	v	v	v	v	v

windows	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2	2	2
	tilt function	1	1	1	0.5	0.5	1	0.5	1	1	1
	∑ part 1	5	5	5	4.5	4.5	5	4.5	5	5	5
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	1	2	2	1	2	1.5	2
	interface quality	1	1	1.5	1	1	1	2	1	1	1
	subjective effectiveness	2	2	2	1	2	2	2	2	1	1
	ecological quality	1	1	2	1	2	2	2	2	1	1
	∑ part 2	8	8	9.5	6	9	9	9	9	6.5	7
	points part 1 + part 2	13	13	14.5	10.5	13.5	14	13.5	14	11.5	12
	∑ x 1.65	21.45	21.45	23.925	17.325	22.275	23.1	22.275	23.1	18.975	19.8

shading	no	0	0	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2	2	2
	exterior shading	1	1	0	0	0	0	0	0	0	0
	∑ part 1	3	3	2	2	2	2	2	2	2	2
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	1	2	2	2	2	2	1	2	1	2
	interface quality	1	1	1	1	1	2	1	1	0.5	1
	subjective effectiveness	1	1	2	2	1	2	1	2	1	1
	ecological quality	1	1	1	2	2	2	2	2	1	1
	∑ part 2	6	7	8	9	8	10	7	9	5.5	7
	points part 1 + part 2	9	10	10	11	10	12	9	11	7.5	9

	ID-Nr.	11	12	13	14	15	16	17	18	19	20
lights	no	0	0	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2	2	2
	task	0	0	1	0	0	0	1	1	0	0
	dimming	0	0	0	0	0	0	0	0	0	0
	on/off	1	0	1	1	1	1	1	1	1	1
	∑ part 1	3	2	4	3	3	3	4	4	3	3
	spatial distribution	2	2	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	2	2	2	2	2	1.5	2
	interface quality	2	1	2	2	2	1	2	1	1	2
	subjective effectiveness	2	2	2	2	2	2	2	2	1.5	1
	ecological quality	1	1	1	2	1	2	2	2	1	1
	∑ part 2	9	8	9	10	9	9	10	9	7	8
	points part 1 + part 2	12	10	13	13	12	12	14	13	10	11
	∑ x 1.35	16.2	13.5	17.55	17.55	16.2	16.2	18.9	17.55	13.5	14.85

heating	no	0	0	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2	2	2
	convective	1	1	0.5	0	0	0	0	1	0	0
	∑ part 1	5	5	4.5	4	4	4	4	5	4	4
	spatial distribution	2	2	2	1	2	2	2	1	2	2
	objective effectiveness	2	2	2	2	1	2	2	2	1.5	2
	interface quality	1	1	2	1	1	2	2	1	1	1
	subjective effectiveness	1	2	2	2	2	2	2	1	1.5	1
	ecological quality	1	2	1	1	2	2	2	1	1	1
	∑ part 2	7	9	9	7	8	10	10	6	7	7
	points part 1 + part 2	12	14	13.5	11	12	14	14	11	11	11
	∑ x 1.65	19.8	23.1	22.275	18.15	19.8	23.1	23.1	18.15	18.15	18.15

	Room EVI	66.45	68.05	73.75	64.025	68.275	74.4	73.275	69.8	58.125	61.8

participants	ID-Nr.	21	22	23	24	25	26	27	28
	male/female [m; f]	f	f	f	f	f	f	f	f
	age	24-26	21-23	21-23	27-29	24-26	24-26	24-26	27-29
	visitor/occupant [v; o]	v	v	v	v	v	v	o	o

windows	no	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2
	turn function	2	2	2	2	2	2	2	2
	tilt function	1	0	0	1	1	1	1	0
	∑ part 1	5	4	4	5	5	5	5	4
	spatial distribution	2	2	2	2	2	2	2	2
	objective effectiveness	2	2	2	1.5	2	2	2	1
	interface quality	1	1	1	1	1	1	1	1
	subjective effectiveness	2	2	2	1.5	2	2	2	1
	ecological quality	1	2	1	1	1.5	1	1	1
	∑ part 2	8	9	8	7	8.5	8	8	6
	points part 1 + part 2	13	13	12	12	13.5	13	13	10
	∑ x 1.65	21.45	21.45	19.8	19.8	22.275	21.45	21.45	16.5

shading	no	0	0	0	0	0	0	0	0
	interior shading	2	2	2	2	2	2	2	2
	exterior shading	0	0	0	0	0.5	0	0	0
	∑ part 1	2	2	2	2	2.5	2	2	2
	spatial distribution	2	2	1	1.5	2	2	2	1
	objective effectiveness	2	2	2	1.5	1.5	2	2	1
	interface quality	1	1	2	1.5	1.5	1	1	1
	subjective effectiveness	1	2	2	1.5	1.5	1	2	1
	ecological quality	1	2	2	0.5	1	1	1	2
	∑ part 2	7	9	9	6.5	7.5	7	8	6
	points part 1 + part 2	9	11	11	8.5	10	9	10	8

	ID-Nr.	21	22	23	24	25	26	27	28
lights	no	0	0	0	0	0	0	0	0
	ambient	2	2	2	2	2	2	2	2
	task	0	0	0	0	0	0	0	1
	dimming	0	0	0	0	0	0	0	0
	on/off	1	1	1	1	1	1	1	1
	∑ part 1	3	3	3	3	3	3	3	4
	spatial distribution	2	2	2	2	1.5	2	2	2
	objective effectiveness	2	2	2	2	1	2	2	1
	interface quality	2	2	2	2	2	2	1	2
	subjective effectiveness	2	2	2	1.5	1	2	2	2
	ecological quality	1	2	1	1	1.5	2	1	1
	∑ part 2	9	10	9	8.5	7	10	8	8
	points part 1 + part 2	12	13	12	11.5	10	13	11	12
	∑ x 1.35	16.2	17.55	16.2	15.525	13.5	17.55	14.85	16.2

heating	no	0	0	0	0	0	0	0	0
	yes	2	2	2	2	2	2	2	2
	radiant	2	2	2	2	2	2	2	2
	convective	0	0	0	1	1	0	0	0
	∑ part 1	4	4	4	5	5	4	4	4
	spatial distribution	2	2	1	1.5	2	0	2	1
	objective effectiveness	2	2	2	2	1.5	1	2	1
	interface quality	1	2	1	1	1	2	2	1
	subjective effectiveness	2	2	1	2	1.5		2	1
	ecological quality	1	2	0	1.5	1	2	1	2
	∑ part 2	8	10	5	8	7	5	9	6
	points part 1 + part 2	12	14	9	13	12	9	13	10
	∑ x 1.65	19.8	23.1	14.85	21.45	19.8	14.85	21.45	16.5

	Room EVI	66.45	73.1	61.85	65.275	65.575	62.85	67.75	57.2

8.3 Feedback from the participants

Participant 1:

- Rooms of department are very similar, which may reduce the difference between EVI points

- The number of points, or the difference between choices need to be finer

Participant 7:

It takes more time than expected.

A different protocol could take other things as for instance plugins for electricity. Would be interesting to see if I would get the same score again.

Participant 8:

There´s no cooling at all. Another version of the protocol could also take into consideration the objects that add some comfort or allow interactions, even if these objects are not part of the building itself (e.g. microwave, coffee machine, fans, hanger, bicycle garage,…)

Participant 9:

- Generally the task was not difficult, because it was explained in detail during the lecture.

- Due to construction work and permanent noise it would be good to include noise into assessment.

- Maybe would be good to add more assessment categories for shading and heating as it was not that clear how to describe situations when blinders are “in the middle of the window”. For heating, maybe heat from electric devices like big printers should be considered.

Participant 10:

- The ecological quality is often very hard to assess –e.g. one doesn´t necessarily know too much about the heating system or the “grey energy” or ecological footprint of different materials of shading devices.

- About the cooling devices: it was a bit difficult to understand how “objective effectiveness” could be defined – if it means “average effectiveness” for the whole room it is rather poor (for the personal table ventilators in the observed case). However, if qualities like air speed, noise levels and cooling effect on the desired area are meant, it could be very good.

- A category for flexibility might also be of use maybe, e.g. if a meeting room can be partitioned into smaller spaces, it might be interesting to see, how well the lighting/heating/ect. Concepts still work.

Participant 11:

- Due to similar structures and equipment of the office many fields could be filled similarly. It would also have been interesting to assess the corridor, because it might have had an influence on the total (EVI x w)-value, since it didn´t seem to be as well-equipped as the other rooms (which is pretty usual for corridors).

From my point of view I would give a stronger weighting-factor than 1 to shading, because it has a huge impact on one´s feeling and behavior in an environment.

Also, I would consider the window-criteria less strong than 1.35, because besides ventilation it also covers lighting, which is also included in artificial lighting.

Participant 12:

I would suggest to make more categories for shading (e.g. between glass shading) and for shading I would rearrange the point system as follows:

no	0
internal	2
between glass	3
external	5

And in this case there is only the dominant one which should count and do not need to be added up.

I would also recommend to examine the interior air temperature and if, and only if it reaches a certain value during summer then consider the cooling system, because in a room where there is no necessity to install a cooling system, the point system should not include it, because it makes it less efficient in the point system.

Participant 13:

The protocol is very objective but there are still some categories when our evaluation might be biased. This is why I think making an average of the collected data from everyone would give closest to reality results.

This way of evaluation is interesting to make us think not only for general rules of building design but also for the feelings of people using the spaces. It would definitely make me think twice.

Participant 14:

Protocol: I was struggling with the objective effectiveness because I thought I was being objective but then comparing my results with others, the results suggested I was too generous. This made me think about how helpful/not helpful this protocol is, and how many people have to agree on some objective aspect in order to get convenient results.

Department: I find this space very comfortable.

Participant 15:

I think the main problem is the lighting system in kitchen and Office 02.

Overall, the protocol is objective and can be used for assessing the space, but I think other categories need to be added such as: Acoustic assessment.

Participant 17:

- Flexibility of the room or the furniture and other utility system were not rated.

- Use of extension wires can affect the work environment as well as a trip hazard, layout of spaces / furniture were not rates i.e., distance of coat rack from entry way and proximity of the secretary area to the entrance.

Participant 18:

It is quite difficult to determine the ecological quality since I am not using the facilities every day.

Participant 19:

I think this is the wrong place to do this experiment because rooms are very similar. I put 2 for the distribution of the windows even if they are only in one part of the room because the situation is like this: Most cases one part of the building is blind or rooms are partially blind because communicate with others inner spaces.

I also think that my judgment about the hotness has been influenced by the temperature present in the room. In order to get data that can be compared I think that in all the rooms the temperature should be the same.

Participant 22:

I think evaluating the space are really difficult because there are things that we can only notice while using there. Also the basis of the evaluation really depends on individuals. And I wonder if the actual data is necessary for evaluating “objective effectiveness” and “ecological quality”