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STUDIES ON USER CONTROL IN AMBIENT INTELLIGENT SYSTEMS

PROEFSCHRIFT

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voor een commissie aangewezen door het College voor Promoties
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adviseur(s):	ir. M.P.J. Aarts

Het onderzoek dat in dit proefschrift wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

CONTENTS

SUMMARY

Humans have an innate need to experience control and be effective in interactions with their environment. At present times, people are surrounded by intelligent systems that take decisions and perform actions based on their context, activities, mood, or anticipated needs and desires. When decisions and actions are automated, there is a risk that people lack the feeling of control and reject the system. An important challenge is to create intelligent systems that assist people by taking over tasks and decision making, while still enabling users to feel in control.

The main question we address in this thesis is to what extent expressive interfaces can be used to design intelligent systems with some degree of autonomy, while providing users the feeling of being in control. The expressive interface refers to the communicative and interactive part of a system that provides feedback and feedforward information about the internal state, intentions, and actions of a system to its user. Expressive interfaces are expected to help users form a mental model of the system and facilitate the interaction. Moreover, we expect that the expressive interface is able to increase users' feeling of control and users' acceptance of intelligent systems. This thesis consists of two parts that examine the main question in different domains. The first part focuses on domestic robots and the second part on automated blinds in offices.

In the first part, we suggest to use personality as a guiding principle for designing the expressive interface and propose a user-centred design process (Chapter 2). This process is applied in three robotic vacuum cleaner case studies (Chapter 3). The results of the case studies demonstrate the feasibility to design robotic cleaners that are perceived to have a personality, which comes to expression in its behaviour, more specifically using motion, light, and sound. Participants prefer a robot cleaner that has a somewhat introvert, agreeable, conscientious, and emotionally stable personality. Furthermore, these studies show that the personality and expressive behaviour can be recognized by users and help them to understand the robot and increase their feelings of being in control. In Chapter 4, we describe the design and evaluation of a personality for the robotic user interface iCat that helped users to find a TV-programme matching their interests. The first study demonstrates that it is possible to convey robot personalities by applying various social cues. The second study shows an interaction between the effects of the robot's personality and level of user control on user preferences.

In the second part, we focus on automated blinds in offices. Chapter 5 reports the results of a field study on the experience and use of automatically controlled blinds with manual override and option to switch off the automatic mode. Most users switch off the automatic mode permanently. Contrary to the expectations, users of the manual mode are not more satisfied with the indoor climate or the daylight conditions than users of the automatic mode. We conclude that it is not the actual control mode that influences user's satisfaction, but whether the experienced level of control is sufficient for their individual needs. Additionally, the field study reveals four blinds usage profiles that vary in the total number of adjustments and the proportion of manual adjustments. The simulation results in Chapter 6 indicate that the average heating and cooling load for users of the automatic mode is lower than for users who switched off the automatic mode. It is problematic from an energy saving perspective that a large majority of users switches off the automatic mode. Therefore, we suggest to improve the acceptance of automated blinds by making users aware of how these systems work and how the blinds usage impacts the energy consumption. In Chapter 7, we present the design of an ambient light feedback device that provides users with information on the actual daylight conditions and upcoming or recommended blind changes. Chapter 8 reports two studies with the ambient light feedback device added to a virtual window with automated blinds. The results show that both the level of automation and the way the system communicates with the user affect the perceived system personality and how much control users perceive. The results further show how these factors affect user's satisfaction with the automated system and the way they use the blinds. The increased adherence to the system's suggestions and the large reduction of user's corrections indicate the potential of the expressive interface to realize energy savings.

In both domains, the notion of personality is useful as a guiding principle when designing the interactions with intelligent systems. The desired personality for an intelligent system varies per application, however in both domains a distinct system personality and behaviour can be designed through expressive interfaces using motion, light, sound, and social cues. The various studies confirm that intelligent systems that do not communicate with users in an appropriate way have a low acceptance. Furthermore, this thesis provides evidence that the level of automation influences the perceived system personality and the perceived level of control. Finally, the results show that the expressive interface can influence the perceived system personality, the perceived level of control, and user's satisfaction with the system.

In sum, this thesis shows the potential of the expressive interface as an instrument to help users understand what is going on inside the system, to feel in control and intervene when needed. The expressive interface might be essential for the successful adoption of the intelligent systems of tomorrow.

SAMENVATTING

Mensen hebben een aangeboren behoefte om controle te ervaren en effectief te zijn in de interactie met hun omgeving. Tegenwoordig zijn velen omringd door intelligente systemen die beslissingen nemen en acties uitvoeren op basis van hun context, activiteiten, stemming, of verwachte behoeften en wensen. Wanneer beslissingen en acties worden geautomatiseerd bestaat het risico dat de mensen geen gevoel van controle meer ervaren en het systeem afwijzen. Een belangrijke uitdaging is om intelligente systemen te creëren die mensen ondersteunen door taken en besluitvorming over te nemen, terwijl gebruikers nog steeds een gevoel van controle ervaren.

De belangrijkste vraag die we behandelen in dit proefschrift is in hoeverre expressieve interfaces kunnen worden gebruikt om intelligente systemen met een zekere mate van autonomie te ontwerpen, waarbij gebruikers het gevoel van controle behouden. De expressieve interface heeft betrekking op het communicatieve en interactieve deel van een systeem dat feedback en feedforward informatie verstrekt aan de gebruiker over de interne toestand, intenties en acties van het systeem. De verwachting is dat expressieve interfaces de gebruikers kunnen helpen bij het vormen een mentaal model van het systeem en de interactie met het systeem vergemakkelijken. Bovendien verwachten we dat de expressieve interface het gevoel van controle bij gebruikers en de acceptatie van intelligente systemen kan verhogen. Dit proefschrift bestaat uit twee delen die de belangrijkste vraag in verschillende toepassingsgebieden proberen te beantwoorden. Het eerste deel richt zich op robots in de thuisomgeving en het tweede deel op geautomatiseerde zonwering in kantoren.

In het eerste deel, suggereren wij om persoonlijkheid te gebruiken als een leidraad voor het ontwerpen van de expressieve interface en stellen we een user-centred design proces voor (hoofdstuk 2). Deze werkwijze wordt toegepast in drie case studies met robotstofzuigers (hoofdstuk 3). De resultaten van de case studies tonen aan dat het mogelijk is om robotstofzuigers te ontwerpen waaraan gebruikers een persoonlijkheid toekennen. De persoonlijkheid komt tot uiting in het gedrag, meer in het bijzonder door gebruik te maken van expressies in beweging, licht en geluid. Deelnemers aan het onderzoek gaven de voorkeur aan een robotstofzuiger met een enigszins introvert, aangenaam, consciëntieus, en emotioneel stabiele persoonlijkheid. Bovendien tonen deze studies aan dat de persoonlijkheid en het expressieve gedrag door gebruikers kunnen worden herkend en dat dit hen kan helpen om de robot te begrijpen en hun gevoel van controle te vergroten. In hoofdstuk 4 beschrijven we het ontwerp en de evaluatie van een persoonlijkheid voor de robot gebruikersinterface iCat die gebruikers helpt om een TV-programma te vinden dat aansluit bij hun interesses. Het eerste experiment laat zien dat het mogelijk is robot persoonlijkheden te creëren door toepassing van verschillende sociale signalen. Het tweede experiment toont een interactie effect aan tussen de persoonlijkheid van de robot en het beschikbare niveau van controle voor de gebuiker op de gebruikerspreferentie van het systeem.

In het tweede deel, richten we ons op geautomatiseerde zonwering in kantoren. Hoofdstuk 5 rapporteert de resultaten van een veldstudie waarin de gebruikservaring van een automatisch zonweringssysteem - met opties voor manuele bediening en de keuze om de automatische modus uit te schakelen - wordt onderzocht. De meeste gebruikers schakelen de automatische modus permanent uit. In tegenstelling tot de verwachtingen, zijn de gebruikers van de handmatige modus niet meer tevreden met het binnenklimaat of het daglicht dan gebruikers van de automatische modus. We concluderen dat het niet de feitelijke bedieningsmodus (automatisch of handmatig) is die de tevredenheid van de gebruiker bepaalt, maar in hoeverre de ervaren mate van controle voldoet aan de individuele controle behoefte. Daarnaast brengt de veldstudie vier verschillende gebruikersprofielen van automatische zonwering systemen aan het licht, die variëren in het totaal aantal aanpassingen en de relatieve hoeveelheid handmatige aanpassingen. De simulatieresultaten in hoofdstuk 6 geven aan dat de gemiddelde verwarmings- en koelbelasting voor gebruikers van de automatische modus lager is dan voor gebruikers die de automatische modus hebben uitgeschakeld. Het is problematisch vanuit een energiebesparing perspectief dat een grote meerderheid van de gebruikers de automatische modus uitschakelt. Daarom stellen wij voor de acceptatie van de geautomatiseerde zonwering te verbeteren door de gebruikers bewust te maken hoe deze systemen werken en hoe het gebruik ervan invloed heeft op het energieverbruik. In hoofdstuk 7 presenteren we het ontwerp van een ambient light feedback apparaat dat gebruikers informeert over de actuele daglicht condities en de aanstaande of aanbevolen aanpassingen van de zonwering. Hoofdstuk 8 rapporteert twee experimenten met het ambient light feedback apparaat gemonteerd op een virtueel raam met automatische zonwering. De resultaten tonen aan dat zowel de mate van automatisering als de manier waarop het systeem met de gebruiker communiceert invloed heeft op de waargenomen systeem persoonlijkheid en de mate waarin gebruikers controle ervaren. Uit de resultaten blijkt verder hoe deze factoren van invloed zijn op de tevredenheid van de gebruikers met het automatische systeem en de manier waarop ze het systeem gebruiken. De suggesties van het systeem worden beter opgevolgd en er is een grote vermindering van het aantal correcties door de gebruiker. Dit laat de potentie zien van de expressieve interface om energiebesparing te realiseren.

In beide domeinen, blijkt het concept van de systeem persoonlijkheid bruikbaar als een leidraad bij het ontwerpen van de interacties met intelligente systemen. De gewenste persoonlijkheid voor een intelligent systeem verschilt per toepassing, maar in beide domeinen kan een duidelijke systeem persoonlijkheid en bijpassend gedrag worden ontworpen door middel van expressieve interfaces met beweging, licht, geluid, en sociale signalen. De verschillende studies bevestigen dat intelligente systemen die niet op de juiste manier met gebruikers communiceren een lage acceptatie hebben. Bovendien levert dit proefschrift bewijs dat het niveau van automatisering de waargenomen systeem persoonlijkheid en het waargenomen niveau van controle beïnvloedt. Tenslotte tonen de resultaten dat de expressieve interface de waargenomen systeem persoonlijkheid, het waargenomen niveau van controle, en de tevredenheid van de gebruiker met het systeem kan beïnvloeden.

Al met al toont dit proefschrift het potentieel van de expressieve interface als een instrument dat gebruikers helpt te begrijpen wat er gaande is in het systeem, controle te ervaren, en in te grijpen wanneer dat nodig is. De expressieve interface kan essentieel zijn voor de succesvolle invoering van de intelligente systemen van morgen.

1 Introduction

1.1 Problem statement

Humans have an innate need to experience control and be effective in interactions with their environment. The self-determination theory describes three main basic psychological needs that are universally recognized to motivate individuals to initiate behaviour that improves their psychological health and well-being (Ryan & Deci, 2000; Ryan, 1995). These are the need for competence, autonomy, and psychological relatedness. The need for competence refers to the desire to control the outcome of an action and experiencing mastery. The need for autonomy relates to the urge to be a causal agent of one's own life, while relatedness refers to the universal need to interact with, be connected to, and care for others. Both the need for competence and the need for autonomy are directly linked to perceptions of control. Decades of research in psychology have demonstrated that a sense of control is a robust predictor of physical and mental well-being (Averill, 1973; Skinner, 1996). Experiencing control is pleasant while a loss of control can make people feel unpleasant, distressed, or even worse than that, depending on how much control is desired.

The three basic needs of competence, autonomy, and relatedness, as well as the perception of control, are known to be important drivers for human behaviour in general, but are also specifically relevant in interactions between humans and technology (Norman, 1994; Spiekermann & Rothensee, 2005; Venkatesh, Morris, Davis, & Davis, 2003). As technology progresses, increasingly intelligent systems take decisions and perform actions based on users' context, activities, mood, or anticipated needs and desires. If such adaptive systems are designed properly and correctly infer what the user wants, little effort is needed from users and the system will be perceived as supportive and easy to use. However, as more decisions and actions are automated, there is a risk that people lack the feeling of control, especially if the wrong decisions or actions are taken (Barkhuus & Dey, 2003; Bellotti & Edwards, 2001; Edwards & Grinter, 2001; Vihavainen, Oulasvirta, & Sarvas, 2009). The basic needs of competence, autonomy, and relatedness might be compromised if the interaction between the user and the intelligent system is not well designed. If the system is too complex and not understandable by a user, it reduces the feelings of competence. If the decisions of the system are not in line with the goals of the user, feelings of autonomy are at stake. Lastly, if the intelligent system cannot properly communicate with people, users will not be able to relate to the system.

Given the above, an important challenge for designers and engineers is to create intelligent systems that assist people by taking over tasks and decision making, but that still enable users to feel in control. Donald Norman states this problem in his book "The Design of Future Things" (Norman, 2007):

> *"So-called intelligent systems have become too smug. They think they know what is best for us. Their intelligence, however, is limited. And this limitation is fundamental: there is no way a machine has sufficient knowledge of all the factors that go into human decision making. But this doesn't mean we should reject the assistance of intelligent machines. As machines start to take over more and more, however, they need to be socialized; they need to improve the way they communicate and interact and to recognize their limitations. Only then can they become truly useful." p9*

Norman suggests that intelligent systems need to be socialized and improve the way they communicate and interact with their users in order to become truly useful. In this thesis, we define the 'expressive interface' as the communicative and interactive part of the intelligent system aiming to 'socialize' the interaction. The expressive interface should provide understandable feedback and feedforward information about the internal state, intentions, and actions of the system to the end-user, in order to help the user form a mental model of the intelligent system, its reasoning, and how to interact with it.

The work presented in this thesis addresses the question how to design intelligent systems that give users the perception of being in control. Can we define a process for designing expressive interfaces? To what extent can expressive interfaces influence users' perception of control, and as a result, users' satisfaction with the intelligent system? The work will be performed in two application domains of Ambient Intelligence: domestic robots and intelligent office buildings.

1.2 Ambient Intelligent systems

At the end of the 20th century, a future vision of 'ambient intelligence' (AmI) was described in which smart technology would be hidden in our environments and supporting our everyday lives (Aarts & Marzano, 2003). The AmI vision was built on the notion of Ubiquitous Computing (UC) (Weiser, 1991). Weiser predicted that ongoing miniaturization in the silicon industry and continuous development in computing and network technology would lead to a world in which people would be surrounded by computers and displays ranging from post-it and pad-sized displays to devices with the size of whiteboards. These devices would all be interconnected by wireless networks and woven into the fabric of our everyday lives. The AmI vision extends the UC vision by emphasizing the system intelligence that makes technology context-aware and respond to events and people in its environment. A second aspect that is emphasized in the AmI vision and an addition to the UC vision is the focus on end-user needs and technology playing a supportive role in the background. Ambient Intelligence research is concerned with intelligent applications of technology that are explored in a user-centred approach, focusing on how the technology can serve human needs. It combines the ubiquity and context awareness elements from the UC vision with intelligence and social interaction between people and technology (Loenen, 2003; Reeves & Nass, 1996). Ambient refers to systems that consist of many networked devices that are embedded in the physical and/or social environments and daily lives of people. Intelligence refers to various forms of reasoning and cognition by the system to address human needs. Various levels of system intelligence are distinguished: context-aware, personalized, adaptive and anticipatory. Context-aware systems recognize users and their situational context or environment and adjust their behaviour accordingly. One level of system intelligence higher, the behaviour of the system can be personalized and tailored to user needs. At the third level of intelligence, these systems are adaptive and change their behaviour in response to different users and variations in the users' context. Finally, the most advanced form of ambient intelligent systems anticipate users' desires, take initiative and make decisions on behalf of users. Since the articulation of the AmI vision, the research field has expanded and many applications have been investigated (Cook, Augusto, & Jakkula, 2009). The initial framework has been extended by others, recognizing the importance of the social intelligence aspects of ambient intelligent systems. Besides the desire to have systems that are context-aware, personalized, adaptive, and anticipatory, it has been proposed that for successful adoption intelligent systems should also be socialized (i.e. adhere to social conventions), empathic (i.e. have a representation of your emotions and motives), and conscious (i.e. apply a model of their inner motives) (De Ruyter, 2010).

Looking back at the UC vision, 25 years later, we can conclude that many predictions have become a reality. We are surrounded by wirelessly connected smart phones (i.e. post-its), tablet pc's (i.e. pads), and flat-screen smart TV's (i.e. whiteboards). Although many aspects of the UC vision have become a reality today, Ambient Intelligent systems have not yet been widely adopted. Indeed, we are surrounded by connected displays and devices and on a daily basis we make use of smart software such search engine and recommenders that use our profiles to provide us better results. But ambient intelligent systems that are responsive to their environments and adaptive to or even anticipating human needs in a successful way are still hard to find. One possible explanation is the hesitation or even reluctance of humans to give away control to machines. Another possible reason is that technology has not been sufficiently mature and robust to fulfil the promise of Ambient Intelligent systems. It seems however, that we are at the forefront of a new era of digitization and technological progress. Increasing performance and decreasing cost of sensors, data storage, data analytics, connectivity, and artificial intelligence will bring intelligent systems such as smart homes, self-driving cars, and smart office buildings within the realm of possibilities for mass adoption.

Table 1 Continuum of levels of automation (Parasuraman, Sheridan, & Wickens, 2000)

		Level of automation
High	10	System decides everything, acts autonomously, ignoring the human
	9	System informs the human only if system decides to
	8	System informs the human only if asked
	7	System executes automatically, then necessarily informs the human
	6	System allows the human a restricted time to veto before automatic execution
	5	System executes a suggestion if the human approves
	4	System suggest one alternative
	3	System narrows the selection down to a few
	2	System offers a complete set of decision/action alternatives
Low	1	System offers no assistance; human must take all decisions and actions

A concept that relates to system intelligence is automation, which refers to a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator (Parasuraman et al., 2000). The level of automation can vary across a continuum from a fully manually operated system to a fully autonomous system (see Table 1).

Furthermore, different aspects of a system can have a different level of automation. Based on a simple four stage model of human information processing, Parasuraman and colleagues proposed a model to apply the various levels of automation to four main system functions: information acquisition, information analysis, decision and action selection, and action implementation. Information acquisition refers to the sensing and data collection of the system. Information analysis involves the processing of the sensed data with algorithms and integration of the data to analyse it. Decision and action selection involves making a selection from a set of alternatives using rules, logic, and inference. Finally, action implementation refers to the actual execution of the action of choice. For these four system functions the level of automation can differ and even during usage of the system the level of automation might adapt to the context.

The level of automation of an intelligent system affects the level of control that is available to the human. At level 10 in the model of Parasuraman, the actual level of control for users is much lower than at level 1, where the human must take all decisions and actions. In some situations, a low level of control for the human might be very acceptable, while in other situations, a high level of control for the human is desirable. It is our belief that it is not the actual level of control available to users that determines users' acceptance of an automated system, but the level of control that is experienced by the user and whether this is appropriate for the task or context. The various constructs of control are discussed in the next section.

1.3 User control

In psychology, the ‘locus of control’ is probably the most studied construct related to control and it refers to “the degree to which persons expect that a reinforcement or an outcome of their behavior is contingent on their own behavior or personal characteristics versus the degree to which persons expect that the reinforcement or outcome is a function of chance, luck, or fate, is under the control of powerful others, or is simply unpredictable.” (Rotter, 1990). People with an internal locus of control believe that one has control over the outcomes of events, while people with an external locus of control tend to attribute outcomes of events to external circumstances. A related concept that has been studied in the field of neuroscience is the sense of agency, which refers to the experience of controlling our own action and producing effects in the external environment (Berberian, Sarrazin, Le Blaye, & Haggard, 2012; Moore & Obhi, 2012). Although the concept of agency could become very relevant to study perceptions of control in Human-Computer Interaction (Limerick, Coyle, & Moore, 2014), the work is still in the early stages and focuses predominantly on short-term sensory interaction loops (intention, action, outcome evaluation). In this thesis, we are more interested in the holistic, long-term, and retrospective feelings of control based on users’ interactions with the intelligent systems.

Many other definitions and constructs of control have been used and studied. An integrative framework for constructs of control is provided by (Skinner, 1996). Skinner distinguishes between objective (or actual) control, subjective control, and experiences of control. Objective control is “the extent of actual control present, as represented by some normatively appropriate assessment of the action-outcome relationship”. Subjective control refers to “an individual’s beliefs about how much control is available”. The experience of control refers to “an individual’s feelings as he or she is interacting with the environment while attempting to produce a desired or prevent an undesired outcome”. For the purpose of this thesis, we distinguish between the actual control that is available to a user of an intelligent system (i.e. how much control the user can objectively exert) and the experienced level of control (i.e. the level of control that the user subjectively experienced) while interacting with the intelligent system.

The experience of control by a user is generally recognized as an important factor influencing user satisfaction, technology acceptance, and intention to use technology (Spiekermann, 2008). For example, Norman investigated the acceptance of agent technology – intelligent systems with some degree of autonomy – and found a positive relationship between the feeling of control and people’s attitude towards the technology (Norman, 1994). Also, in the widely adopted Technology Acceptance Models the experience of control plays an important role. The original Technology

Acceptance Model (TAM) was developed to predict the acceptance of information systems (Davis, 1989). Davis proposes that two constructs, namely perceived usefulness and perceived ease of use, determine users' intention to use a technology. Perceived usefulness is defined as "the extent to which a person believes that using a technology will enhance her/his productivity" and perceived ease of use as "the extent to which a person believes that using a technology is free of effort". These two constructs are affected by the system characteristics. Perceived ease of use is also expected to influence perceived usefulness - when a technology is easier to use it will also be perceived as more useful to the user. Perceived control was found to be a determinant of perceived ease of use and consequently of technology acceptance in the extended TAM model of Venkatesh and colleagues (Venkatesh et al., 2003). On the other hand, in some situations a reduced feeling of control can be acceptable if the increased usefulness of the system is greater than the loss of control (Barkhuus & Dey, 2003). The TAM model has been extensively validated in several studies and also its applicability beyond the field of information systems has been investigated. For example, the TAM model has been extended to predict the acceptance of automated systems by including the constructs compatibility and trust (Ghazizadeh, Lee, & Boyle, 2012). The authors defined compatibility as the appropriateness of the level of automation, or whether the level of automation matches the user's desired level of system autonomy. Trust was defined as a social emotion that influences the interaction between people and technology, consisting of the three dimensions predictability, dependability, and faith that evolve over time; based on (Rempel, Holmes, & Zanna, 1985). As mentioned before, with increasingly automated systems the perception of control will become an even more important factor in the acceptance of this technology. In this thesis, we will focus on experience of control and not elaborate further on trust in automation as this well studied topic (J. Lee & Moray, 1994; J. Lee & See, 2004; Muir & Moray, 1996; Muir, 1994) is considered out of scope.

1.4 Expressive Interfaces

It is a challenge to design an intelligent system in such a way that it supports our everyday activities, complements our skills and adds to our pleasure, convenience and accomplishments, but not to our stress (Norman, 2007). One of the key problems is the lack of common ground between the human and the system, which impedes the effective communication between the two. Common ground refers to the collection of "mutual knowledge, mutual beliefs, and mutual assumptions" that is essential for communication between interaction partners (Clark & Brennan, 1991). In human-machine interaction important elements that can help to create a common ground are missing, including the acknowledgement of understanding the communication partner through verbal, nonverbal, formal, and informal acknowledgments. Intelligent systems respond to their environments and behave differently every time, making them less predictable. How do people know what the system is doing and whether it is doing the right thing? Intelligent systems take autonomous decision and actions using algorithms that are hidden from their interaction partners. How can people understand the logic behind this decision making and build up a mental model of the system?

The questions and challenges mentioned above have been identified by several other researchers (Bellotti & Edwards, 2001; Edwards & Grinter, 2001; Vermeulen, 2014). However, the problem of poor communication between humans and intelligent machines still exists in most of today's intelligent systems. Norman formulates a number of rules for designers of 'smart' machines to make the interaction between human and machine understandable and effective (Norman, 2007):

- Provide rich, complex, and natural signals.
- Be predictable.
- Provide good conceptual models.
- Make the output understandable.
- Provide continual awareness without annoyance.
- Exploit natural mappings.

The expressive interface as we define it in this thesis is hypothesized to be instrumental for designers to meet these six basic rules for proper human-automation interaction. It is the touchpoint between the human and the other intelligence: the machine.

1.5 Organization of the thesis

Based on the above, we believe that one of the key aspects determining whether people will accept - and perhaps even enjoy - to be surrounded by intelligent systems is to what extent they feel in control. Intelligent systems should be there to make our lives easier and more enjoyable, not more complicated.

The main research question addressed in this thesis is to what extent expressive interfaces can be used to design intelligent systems that have a certain degree of autonomy to perform actions on users' behalf, while still providing users the feeling of being in control. Following the reasoning of Norman (Norman, 2007), it is hypothesized that expressive interfaces can help to communicate information about the internal state, intentions, and actions of the intelligent system towards the user.

Expressive interfaces are expected to help users form a mental model of how the intelligent system works and facilitate the interaction between the user and the system. The expressive interface is further expected to be able to increase users' feeling of control, as the interface affects three important determinants of control: information, choice and predictability (Skinner, 1996). Consequently, expressive interfaces might increase users' satisfaction with and acceptance of intelligent systems.

This thesis consists of two parts that address the main research question in different domains. The first part focuses on the domestic environment in a functional robotic application (cleaning) and an entertainment robotic application (TV-assistant), while the second part focuses on the intelligent office environment. By investigating the research question in these different application areas, we can explore whether there are any generic and/or application-dependent user preferences with respect to expressive interfaces, levels of automation, and perceptions of control. The domains have some aspects in common that motivate their inclusion in this thesis and the execution of empirical studies to investigate the main research question in the respective domains. In both domains, there are clear drivers for increased automation and first instantiations of intelligent systems are on the market. In both domains, the intelligent systems operate in an environment with people and implicitly and explicitly interact with them. The human is clearly in the loop; there is no full automation nor complete manual control but a situation of mixed control. Besides these commonalities, there are a few differences that make it interesting to include both domains in our study and compare the results.

The domestic robot is a very clear instantiation and embodiment of an intelligent system in consumer homes. While the presence of domestic robots has for a long time been limited to science fiction movies, the first commercial applications of domestic robots such as robotic vacuum cleaners have now entered people's homes. The main driver for adoption of autonomous vacuum cleaners is the convenience to hand over an unpleasant cleaning job to technology. Despite this clear and appealing benefit, consumers have not yet widely adopted robotic vacuum cleaners. Hence, it is interesting to study whether expressive interfaces can influence users' perceptions of domestic robots and increase adoption of this technology. Finally, domestic robots typically have rich means to express themselves through motion, sound, and lights, making it suitable carriers for research on expressive interfaces.

The second part of this thesis focuses on intelligent office buildings, and more specifically on automated blinds systems. While in the case of domestic robots, the intelligence has a clear physical instantiation and embodiment, for the automated blinds system the intelligence is distributed into various parts, together forming the intelligent system, and has a more ambient representation. A reduction of the energy consumption is the main driver for the installation of automated blinds in office buildings. Nowadays, automated blinds systems are adopted in many office buildings, but the acceptance of fully automated blinds system is often low (Galasiu & Veitch, 2006). Therefore, it is interesting to study whether expressive interfaces can increase acceptance of this technology. Finally, the means of automated blinds systems to express themselves are less rich than for domestic robots. For robots, humanlike or lifelike expressions are to be expected and often used in existing designs. For the more abstract and simple embodiment of a blinds system, it is less clear how it can express its status, intentions, and actions towards users.

To answer our main research question - to what extent expressive interfaces can be used to design intelligent systems that have a certain degree of autonomy to perform actions on users' behalf, while still providing users the feeling of being in control - the first question that we address in Chapter 2 is whether we can define a user-centred design process to develop expressive interfaces for intelligent systems. Based on previous work, we propose to use the concept of personality as a guiding principle for designing the interface and interactions with intelligent systems, in particular robotic appliances.

In Chapter 3, the proposed design process is applied in three case studies on the design of robotic vacuum cleaners. Through the case studies, we try to answer the questions what kind of personality users expect from a robotic vacuum cleaner and how to express this personality in its behaviour. We also describe how the desired personality is implemented in the robotic vacuum cleaners by using motion, lights, and sound. Furthermore, we evaluate how people perceive this expressive interface and whether they recognize the robot's personality as intended by the design.

Chapter 4 describes the design and evaluation of a personality for the robotic user interface "iCat" that helps users to find a TV-programme that fits their interests. Two studies were conducted. In the first study, we investigate to what extent it is possible to create convincing and distinct personalities in a robot by an expressive interface using speech, facial expressions, motion, and linguistic style. In the second study, we investigate what personality users prefer for the robotic TV-assistant, what level of control they prefer (i.e. how autonomous the robot should behave), and how personality and the level of control relate to each other.

In Chapter 5, we shift our focus to the domain of building automation and describe a field study on how building occupants experience and use an existing automated blinds system. By observing how people currently use these systems, insights can be generated on the level of acceptance of automated blinds systems by users and the potential reasons for rejection that might be addressed by expressive interfaces. We try to answer the question how these automated blinds systems are used in reality and to what extent these systems are accepted by their users.

In Chapter 6, we investigate the impact of different usage patterns of an automated blinds system – and whether people use the automatic mode of the blinds or not - on heating and cooling loads in an office building. We examine the potential costs of rejection of automated blinds systems by its occupants.

Chapter 7 describes the design of an automated blinds system with an expressive interface. The design process as presented in Chapter 2 is applied to the design of an automated blinds system. It addresses the questions what kind of personality people expect from an automated blinds system and how this personality can be expressed and implemented in the automated blinds system.

In Chapter 8, we evaluate the expressive interface that was designed to communicate the status and intentions of the automated blinds system to the building occupants. The chapter reports the results of two studies in which we investigated the effect of the level automation and the type of system expressiveness on users' satisfaction with and usage of an automated blinds system. We address the question to what extent expressive interfaces can increase users' perception of control, and consequently, users' satisfaction with the intelligent system.

Finally, in Chapter 9 we present the main conclusions of the work. The key findings of the first and second part of the thesis are summarized and compared. Implications for future design of ambient intelligent systems are provided at the end of the chapter.

Part I: Domestic Robots

2 Designing domestic robots with personality

Research has shown that robots tend to induce the perception of personality through their behaviour and appearance. It has therefore been suggested that the concept of personality can be used as a guiding principle for designing the interface and interactions with robotic appliances. A well-defined and clearly communicated personality can assist users to form a mental model of the robot and facilitate their interactions with it. But this raises questions about what kind of personality to design for a robot and how to express this personality in its behaviour? A user-centred design process is described that supports the development and evaluation of personality profiles and expressive behaviour for robotic products.

This chapter is based on the following publication:

Meerbeek, B.W., Saerbeck, M. (2011). Designing domestic robots with personality. In: K. Dautenhahn & J. Saunders (Eds.), *New Frontiers in Human–Robot Interaction (Vol. 2,* pp. 257–278). John Benjamins Publishing.

2.1 Introduction

2.1.1 Domestic robots

Traditionally, robotic technology has been used in controlled industrial settings, for example in car manufacturing. However, advances in technology increasingly allow robots to provide services directly to people, at our workplaces and in our homes (Fong, Nourbakhsh, & Dautenhahn, 2003; Forlizzi & Disalvo, 2006). These domestic robots can be used for household tasks, security tasks, entertainment purposes, and educational purposes. Although nowadays a technical explanation of an appliance is provided for the user, this will become increasingly difficult in the future with complex products such as autonomous robots. Users cannot be expected to learn about sensors, actuators, and control architectures. Instead, users will form a mental model of the system which is about their beliefs of the system. Individual users form their own mental model. This is not necessarily the same as the factual working of the system or the systems designers model (Norman, 1986). An expressive interface which expresses the robot's intentions and actions could help users to make sense of the robot's behaviour and form expectations, so they understand which actions are needed from their side. More specifically, a good mental model allows the user to make concrete predictions about the device's behaviour in response to a command. Meeting these expectations supports the feeling of understanding the device and being in control.

The design of expressions and social responses poses new challenges to the design process (Wrede et al., 2004). The main approach to trigger and utilize people's understanding of social interaction is to equip robots with life-like and social characteristics (Breazeal, 2004; Goodrich & Schultz, 2007). The important difference to traditional interaction with devices is that robots are becoming increasingly autonomous and can be perceived as a team member or interaction partner rather than a mere tool. In fact, research has shown that machines will induce the perception of being life-like and having a certain personality, through their appearance and behaviour (Reeves & Nass, 1996). In line with these observations, Fong and colleagues present an overview of what they call socially interactive robots, i.e. robots that exhibit human-like social characteristics (Fong et al., 2003). Some examples of these characteristics are the ability to express and perceive emotions, to communicate with natural language, to establish and maintain social relationships, to use natural cues in verbal and non-verbal behaviour, and to exhibit distinctive personality and character.

2.1.2 Animacy and anthropomorphism

Over sixty years ago Heider and Simmel demonstrated that people attribute motivations, intentions, and goals to simple inanimate objects, based solely on the pattern of their movements (Heider & Simmel, 1944). More recent research showed that even the motion of a single featureless dot can be enough to convey the impression of animacy - the state of being alive and animate (Tremoulet & Feldman, 2000). Traditionally, constructs such as attribution, social communication, and personality have been studied in the fields of psychology and social sciences. With the emergence of autonomous robots, they become increasingly relevant for the design of electronic products. Field tests, such as the ethnographic study with the robotic vacuum cleaner Roomba revealed that the use of an autonomous robot in a social environment (i.e. the home) had an impact on social roles and cleaning habits of the participants (Forlizzi & Disalvo, 2006). This effect occurred even though the robot was not designed for social interaction. Dautenhahn and colleagues conducted an exploratory study to investigate what people expect from a robot companion (Dautenhahn, Woods, Kaouri, Walters, & Werry, 2005). They found that people's expectations of the robot's behaviour match to a certain degree the expectations of the behaviour of a social communication partner. For example, it might be expected that the robot moves with similar speed as humans, that it doesn't invade the social space by coming too close and that it is polite (e.g. by giving way). These expectations appear to be restricted to the communication with a device, as only a few participants wanted the robot to take social roles, such as becoming a friend. Instead, the notion of an assistant or servant was preferred. Interestingly, the majority of participants reported a preference for predictable behaviour. While a believable social character should provide variation in the short behaviour sequences and expressions (e.g. non-repetitive movements), the long-term, aggregated behaviour should be predictable. Higher level constructs such as behaviour traits and personality can be useful. Intuitively, people know what to expect from another person even though the behaviour is never exactly the same. For example, people expect a response when they greet each other. A coherent personality expressed through behaviour can therefore also help to understand and predict the behaviour of a robotic appliance.

The cognitive process of attributing life-like features is also known as anthropomorphism (when attributing human-like characteristics) or zoomorphism (when attributing animal-like characteristics). A debated topic is whether designers should use anthropomorphic features in robots. Some argue that robots should closely imitate humans to serve as an ideal interface (Ishiguro, 2006). Others put this view in perspective, arguing that anthropomorphic features have to be carefully balanced with the available technology in order not to raise expectations that cannot be met (Duffy, 2003). Duffy stresses that the goal of using anthropomorphic features is to make the interface more intuitive and easy to use; it is not to copy a human. In line with his argument, the design process presented in this chapter aims to operationalize anthropomorphic or life-like features to make the interaction with the robot more intuitive and easy. The main objective of this design process is to create and manage a coherent personality in the robot appliance. The next section gives some background on the concept of personality and explains how it can be helpful in designing appropriate life-like features in a robot. We believe the concept of personality is particularly suitable for designing robotic applications and will explain the rationale for using personality in section 2.1.3. However, it should be noted that other psychological concepts can be used to achieve a similar effect, including for example emotion, mood, attitude or social intelligence (Bartneck, 2002; Bates, 1994; De Ruyter, 2010; Saini & De Ruyter, 2005), but it is considered outside the scope of this thesis to discuss and review these alternatives.

2.1.3 Personality

Personality is an extensively studied construct in psychology. As McAdams and Pals point out there is no comprehensive and “integrative framework for understanding the whole person” (Mcadams & Pals, 2006, p.204). Carver and Scheier present an overview of personality theories categorized along seven perspectives, including the biological, psychoanalytic, neo-analytic, learning, cognitive self-regulation, phenomenological, and dispositional perspectives (Carver & Scheier, 1995). In brief, these theories agree on the general characteristics of personality: it is tied to the physical body; it helps to determine how the person relates to the world; it shows up in patterns (recurrent and consistent); and it is displayed in many ways (in behaviour, thoughts, and feelings). Additionally, an individual personality contributes to the uniqueness of a person.

As the presented work concentrates on the expression of personality as a pattern of traits, research on dispositional traits was considered most relevant. The dispositional perspective is based on the idea that people have relatively stable qualities (or traits) that are displayed in diverse settings. Dryer stresses three focus points to maintain the coherence of a person’s personality (Dryer, 1999):

1. cohesiveness of behaviour
2. temporal stability
3. cross-situation generality

Research combining several trait theories that focused on labelling and measuring people’s personality using the terms of everyday language (e.g. helpful, assertive, impulsive, etc.) led to an emerging consensus on the dimensions of personality in the form of the Big-Five theory.

Table 2 Five-factor model of personality: dimensions and facets (McCrae & Costa, 1987)

Dimension	Facets
Extraversion	warmth, gregariousness, assertiveness, activity, excitement-seeking, positive emotion
Agreeableness	trust, straightforwardness, altruism, compliance, modesty, tender-mindedness
Conscientiousness	competence, order, dutifulness, achievement, striving, self-discipline, deliberation
Openness	fantasy, aesthetics, feelings, actions, ideas, values
Neuroticism	anxiety, angry hostility, depression, self-consciousness, impulsiveness, vulnerability

The Big-Five is a generally accepted theory that is currently supported by most empirical evidence (Mcadams & Pals, 2006). It describes personality in five dimensions: extraversion, agreeableness, conscientiousness, neuroticism, and openness to new experiences. Table 2 provides a list of the five dimensions and some of their facets. These facets indicate the scope of each dimension and the variety of aspects within each dimension. Studies have used personality theories such as the Big Five to assess people's perceptions of robot personality (Kiesler & Goetz, 2002; Walters & Syrdal, 2008). However, the Big-Five theory of personality can also be used as a framework to describe and design the personality of products, and in particular of robots. Norman describes personality as: "a form of conceptual model, for it channels behaviour, beliefs, and intentions into a cohesive, consistent set of behaviours" (Norman, 2001) . Although he admits that this is an oversimplification of the complex field of human personality, his statement indicates that deliberately equipping a robot with a personality helps to provide people with a mental model of the robot's behaviour. Other researchers have investigated personality in the context of the physical design or appearance of products (Govers & Schoormans, 2005; Mugge, Govers, & Schoormans, 2009). It should be noted that the work in this thesis focuses on the personality that is expressed by the dynamic aspects of autonomous behaviour rather than by the physical appearance of the product. The challenge is to design a personality that is reflected in the robot behaviour, fits the task, and meets the expectations of the user.

In the domain of socially assistive robotics, pioneering work has been presented by Tapus and others (Tapus, Ţăpuş, & Matarić, 2008). They used personality concepts to modify the behaviour of an assistive robot. Based on the similarity attraction hypothesis (Byrne, 1971), they adjusted the behaviour of a robot to match the personality of the participants along an extroversion-introversion personality dimension. Even though it can be argued whether there exists a preference for similar personalities or whether opposites attract, this example demonstrates how personality can be used as a design guideline. Based on the personality profile the behaviour was updated along three parameterized dimensions of distance, verbal communication (including pitch), and activity. However, only one dimension of personality was taken into account (extraversion). The design of rich and elaborate personalities currently relies on the intuitions of a designer.

2.1.4 Research questions

A formalized design process is required that supports the development and evaluation of rich personality profiles for autonomous systems. Important questions arise when explicitly designing a personality for a robot in a given application. What kind of personality is appropriate for the robot to facilitate the interaction with humans? How might the robot express the personality through its behaviour? This chapter describes how personality can be addressed in the design process.

2.2 Previous work

Careful design of robotic behaviour appears to be a crucial factor for the acceptance and success of a robot application (Forlizzi & Disalvo, 2006). Several approaches to design personalities for expressive autonomous products have been suggested. However, up to now there is neither a consensus on general design rules for personality design nor a unified design process. This section summarizes some of the existing approaches relevant to personality design. Traditionally, there have been three main perspectives on designing the expressive behaviour of a robotic product:

1. a technology perspective
2. an artistic perspective
3. a user-centred perspective

These three approaches are illustrated next.

2.2.1 Technology perspective

When the first robots were constructed, their behaviour was fully determined from a technological, functional point of view. The behaviour was implicitly implemented by engineers who had the technological expertise to control the hardware. Hence, robotic behaviour resulted from functional requirements such as navigating via the shortest path to a certain location, hardware constraints such as maximum speed, and correction movements to compensate for hardware inaccuracies. Several architectures for designing the behaviour of interactive robotic characters have been proposed (Duffy, Dragone, & O'Hare, 2005; Snibbe, Scheeff, & Rahardja, 1999). In the subsumption-architecture proposed by Brooks, the overall behaviour of the robot is explicitly an emergent feature that is composed from simpler basic actions and therefore difficult to control on a macro level such as personality (Brooks, 1991). How the user perceives certain behaviour had only later been taken into account. For example, Kawamura and colleagues stressed the necessity of service robots being easy to use, but base many design decisions on the technical constraints of a particular robotic platform (Kawamura, Pack, Bishay, & Iskarous, 1996). Neubauer takes a more analytical approach to the design of artificial personalities (Neubauer, 2004). He explores the application of Carl Jungs theory of personality in design of artificial entities such as chat bots or avatars on the web. He classifies personalities using the scheme of Jung and categorizes them according to what personality type is implementable with a computer, given current understanding of artificial life.

The main characteristic of these approaches is the focus on specific technical implementations. Even though the underlying technology is essential for the feasibility of a robotic application, it tends to narrow the design space by technical limitations rather than by user insights. A striking example for the mismatch between a technical optimal solution and a user preferred solution is the organization of cleaning patterns of a vacuum cleaning robot. Kim and colleagues showed that an area based approach that is logical and understandable for a user (i.e. cleaning the floor area by area; first the living area, then the dining area, then the kitchen) might be preferable over the technically optimal cleaning path (i.e. optimal coverage of the floor in the shortest time), even though it lowers the overall cleaning performance (Kim, Lee, Chung, & Kim, 2007).

2.2.2 Artistic perspective

In contrast to a technical approach, an artistic approach is mainly concerned with the expression of behaviour. The focus is not on the functionality of a robot, but on how people perceive its behaviour. The underlying idea of conveying messages through expressive behaviour is borrowed from the field of movies and animations. The most cited set of design guidelines are the 12 design principles of Disney Animation (Thomas & Johnston, 1981). The design principles serve as guidelines for creating believable expressions in artificial characters and are widely applied in the movie industry. Van Breemen was one of the first to apply animation technology to the development of robots and showed that by simply adhering to some of the animation principles, the behaviour of a robot appears to be more life-like (Breemen, 2004). Takayama and others have applied animation principles to let robots express forethought and reactions to outcomes (Takayama, Dooley, & Ju, 2011). However, traditional animation guidelines cannot directly be translated to the design of robotic behaviour (Saerbeck & Holenderski, 2009). For example, artificial screen-based characters do not need to adhere to physical laws, which allows them to perform actions that are impossible for embodied robots. Furthermore, scripted behaviour sequences in movies can be highly optimized due to the available meta-information about the scene. In contrast, robotic behaviour design cannot rely on a predefined perspective in which the robot will be observed. The behaviour has to be adjustable to fit a situation at run-time.

A general characteristic of the artistic approach is that it relies on the artistic skills of the designer, which are difficult to quantify. Several guidelines have therefore been developed to support the designer when making and justifying choices, but they do not replace the need for creativity and inspiration. Dautenhahn refers to comic design and identifies two design dimensions:

1. universal design
2. abstract design

For the first dimension, the designer abstracts out universal features of a behaviour or an expression so that people can recognize it and identify themselves with the character (Dautenhahn, 2002). For the second dimension, the designer has artistic freedom to add specific features that can best be described as artistic style.

2.2.3 User-centred perspective

In the process of designing interactive robotic characters, many design principles have been borrowed from the field of human-computer interaction. The user-centred approach is characterized by a strong focus on the user. The key principle is an iterative design cycle to evaluate and refine the system. Gould and Lewis proposed three design principles in human-computer interaction (Gould & Lewis, 1985):

1. early focus on the user and the task
2. empirical measurement
3. iterative design

The first principle indicates the designer must have close contact with the user to understand the user and the task. One method for learning from users is to interview them. Initial interviews should be conducted before the first design prototype. The second principle demands careful investigation of how people interact with the device at hand. The authors warn the designers not only to present a system to the users, but also to measure usability. The third principle assumes that it is almost impossible to get a system right the first time, hence promoting an iterative design cycle.

Many user-centred design approaches have been reported in the literature. For example, Ljungblad and colleagues used the concept of personas to guide their design process for creating personalities for artificial agents (Ljungblad & Walter, 2006). From interviews of participants they generated use cases and scenarios. The notion of designing and validating scenarios was useful for designing the personality for the personal robot PaPeRo (Osada, Ohnaka, & Sato, 2006). The scenarios included a basic set of interactions with the user, placed in the context of an application. The process of validating the scenarios can yield unanticipated insights. For example, for the PaPeRo robots, the authors found that users attributed different personalities and roles to robots of different colours. A blue PaPeRo was perceived as the leader of the other PaPeRos, and a yellow one was perceived as if it were the youngest. This feedback was taken into account by changing the behaviour to enhance these expectations, for example by changing the utterances of the robot. Another full design process is presented by Jacobsson and colleagues, in which they designed a small tangible robot for interaction (Jacobsson, Fernaeus, & Holmquist, 2008). Throughout the design process personas were created and behaviour was prototyped for concrete scenarios. The authors focussed on a technique called *marginal practices*; that is investigating interaction patterns in uncommon situations to open up the design process for new ideas. Even though such scenarios and mock-ups have proven useful in many design studies, the authors warned in earlier studies not to give wrong impressions with the mock-ups or to portray something that is not there (Ljungblad & Walter, 2006).

Despite a focus on the user, the creativeness of a designer still plays an important role in the design process. Friess examined real world practices used in the design process and found that during everyday interaction not only usability evidence is used to defend design decisions (Friess, 2008). Also, pseudo evidence and simple common sense are used. Höök proposes a user-centred process and applies it to three case studies (Höök, 2004). She investigates how affective user interfaces can be designed and how they can be evaluated. She criticizes formal approaches of user studies, since they do not capture the fine grained facets of personality and affective design. She proposes a two layered design approach. The first layer focuses on usability, that is, on verifying whether basic design intentions such as emotional expressions are understood by the user. The second layer verifies whether affective aspects in the design contribute to the experience of the user. The user becomes an integral part of the design process, but instead of formally evaluating the system, the user can provide a broad interpretation of his or her experience. Furthermore, she points out that traditional user studies search for an average user that does not exist. Instead of generalizing, affective design should focus on how the individual interacts with the system. Finally, Riek and Robinson present a paradigm for the design of interactive robots called affective-centred design (Riek & Robinson, 2009). By drawing on the disciplines of human-computer interaction (HCI), affective computing, and human-robot interaction (HRI), they suggest techniques that robot designers can use to ensure interactions with their robots are enjoyed and accepted by users.

2.3 Personality design process

Although several approaches for designing personalities of expressive autonomous products have been proposed, there is no unified practical process that integrates a user-centred, artistic, and technical approach to designing product personalities (Meerbeek, Saerbeck, & Bartneck, 2009). In this section, a process to design personality and expressions for domestic robots is described. The process consists of five main steps, namely creating a personality profile, expressing the personality in behaviour, specifying behaviour in design rules, implementing the behaviour and evaluating the behaviour with end-users. The focus of this section will be on the general process (see Figure 1). In other chapters of the thesis, the process will be illustrated with specific examples.

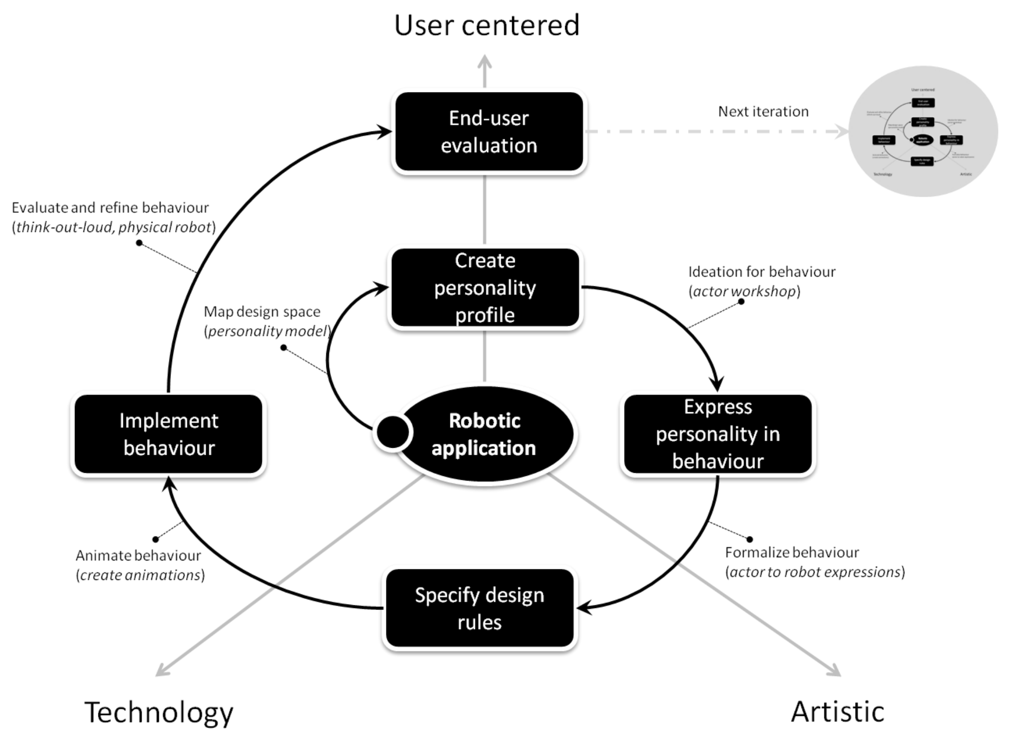


Figure 1 Visualization of the design process for robot personality

2.3.1 Create a personality profile

The proposed design process uses the notion of personality as a guiding principle to create consistent and understandable behaviour, to facilitate natural (social) interaction, and to make products more attractive for users. Therefore, the first question that needs to be addressed is what kind of personality the robot should have. A user-centred approach can be taken during this phase of the process, for example interviews or focus group sessions with potential end-users. The Big-Five theory of personality can be used as a reference framework to discuss the desired personality. A more artistic approach can also be used in this phase of the design process. For example, techniques to create characters can be borrowed from the domain of movies, theatres, and literature. Creative story writing techniques and backstories (i.e. a set of events invented for a plot, presented as preceding and leading up to that plot explaining personality and behaviour of the characters in the plot) can be helpful to create rich and believable personalities for a particular application context. Obviously, a mix of these approaches can be used as well.

2.3.2 Expressing personality in behaviour

The desired personality of a robot, as described in the personality profile, needs to be reflected in its behaviour. Following a user-centred approach, interviews or focus groups can be held with end-users in which they can come up with example behaviours that match with the personality profile defined in the first step. Since it might be difficult for end-users to define how a personality can be expressed in the behaviour of a product (users are not designers), it can be beneficial to include a team of designers that can translate the personality profile into product behaviour, making use of their design skills and knowledge. In a more artistic approach, actors can be asked to sympathize with the created personality profile and then act out the robot behaviour.

2.3.3 Specify design rules

The previous step in the design process results in an understanding how to express the desired robot personality in its behaviour. Based on this understanding, the behaviour is specified in design rules that serve as input for implementation in the robot. The design rules can be formulated in a written set of rules or guidelines. Alternatively, a more visual approach can be followed using animated storyboards to sketch the design rules for the robot behaviour.

2.3.4 Implement behaviour

User studies need a method to showcase the behaviour and assess whether the behaviour reflects the desired personality and is appreciated by consumers. Often, the design rules as formulated during the previous step of the design process are too abstract to evaluate with potential end-users. Ideally, end-users are confronted with the real robot behaviour, but the difficulty is that implementation and evaluation of robot behaviour are time consuming tasks. Therefore, a two-stage approach is suggested. First, the behaviour is implemented, evaluated, and refined in a virtual environment. Alternatively, 'experience prototypes' are created that can convey the user experience as envisioned for the final product, but parts of the functionality are simulated (e.g. through Wizard-of-Oz). Also, a video prototype of the robot behaviour can be made. When the resulting behaviour is satisfactory, implementation and evaluation continues with the physical robot platform.

2.3.5 Evaluate behaviour

Once (part of) the robot behaviour is implemented, it can be evaluated with stakeholders and end-users. Depending on the type of questions that need to be answered various methods can be used, but typically a mix of qualitative and quantitative methods provides the richest information. Given the complex nature of interactions between humans and robots or intelligent systems, qualitative methods are very useful to understand how the large variety of related factors influence the user experience. Particularly, a think-out-loud method is useful as participants verbalize what they think while observing the behaviour of the robot. This provides useful insights whether the behaviour is perceived as intended by the designer. In addition, a post-task semi-structured interview can be used to retrospectively discuss a number of topics with participants and understand how people perceive and interpret the behaviour. Questionnaires are useful to more systematically assess the perceived personality of the robot system or to compare the impact of different behaviours on user experience aspects, including perceptions of control, ease of use, and other usability aspects.

2.4 Conclusion

This chapter describes a process for designing the behaviour of a domestic robot and proposes it as a way to design a personality and appropriate expressions for intelligent systems. The process consists of five main steps, namely:

1. creating a personality profile
2. expressing the personality in behaviour
3. specifying the behaviour in design rules
4. implementing the behaviour
5. evaluating the behaviour with end-users

The proposed design process integrates technical, artistic, and user-centred approaches to design a personality for a robotic application. A user-centred approach is suggested to explore what kind of personality people would like a robot to have. Based on this user knowledge, an artistic perspective should be taken to identify expressions and behaviour of a robot with a particular personality. Later in the process, a more technological perspective guides the translation of expressions and behaviours into concrete and implementable solutions for a particular robot embodiment, taking into account its requirements and constraints. In chapter 3, the proposed design process is applied to three design case studies of robotic vacuum cleaners and the main lessons learned about the design process will be shared.

Although the design process focuses on designing personality and behaviour for robotic applications, it is believed the process can be applied to a broad range of intelligent systems. In chapter 7, the same design process will be applied to an automated blinds system in an office setting.

3 Robot vacuum cleaner personality and behaviour

This chapter describes the personality design process of chapter 2 applied to three robotic vacuum cleaners case studies: Eagle, Falcon, and Dusty. For each case study, the various process steps are explained in detail and the results of each step are described. The chapter ends with a summary of the main findings and lessons learned while applying the proposed design process to three practical case studies.

This chapter is based on the following publications:

Meerbeek, B.W., Saerbeck, M. (2011). Designing domestic robots with personality. In: K. Dautenhahn & J. Saunders (Eds.), *New Frontiers in Human–Robot Interaction (Vol. 2,* pp. 257–278). John Benjamins Publishing.

Hendriks, B., Meerbeek, B., Boess, S., Pauws, S., & Sonneveld, M. (2011). Robot vacuum cleaner personality and behavior. *International Journal of Social Robotics, 3*(2), 187-195.

3.1 Introduction of domestic robot vacuum cleaners

Since the introduction of Rosie as the housekeeper of the Jetson's family in the 1960's, people have dreamt about robotic cleaners and household assistants (Hanna & Barbera, 1962). While for ages it was considered science fiction, it became a reality when in the beginning of the 21st century robotic vacuum cleaners entered the consumer market. Electrolux launched the very first commercially available robotic vacuum cleaner Trilobite in 2001. Since then, many companies followed including Samsung, LG, Dyson, Philips, Neato, and iRobot. More than a decade after the introduction of the Trilobite, the market for robotic vacuum cleaners is steadily growing. Robotic vacuum cleaners are becoming more mainstream products and the most successful company in this field iRobot sold over 15 million units. While the robotic vacuum cleaners currently on the market by no means resemble Rosie and most often look like a flat disc on wheels, the introduction of these devices does impact the household in another way than most other domestic appliances or traditional cleaning tools. People start to form social relationships with the robot, give it names, and attribute human-like traits to it (Forlizzi & Disalvo, 2006).

The next sections present three case studies on robotic vacuum cleaners. The previous finding that people attribute a personality to their robotic cleaners was taken as a starting point for these case studies. Can we exploit the fact that people attribute human-like characteristics and personality traits to the device? What kind of personality would people prefer for a robotic vacuum cleaner? And can a robot personality serve as a mental model and facilitate the interactions people have with the robotic cleaners?

3.2 Case 1: Eagle

3.2.1 Introducing Eagle

Eagle is the name of a product concept of an autonomous vacuum cleaner that consists of two main independently moving components: a large canister and a small nozzle, connected through a hose (see Figure 2). Eagle is connected to the mains with a power cord and therefore has similar suction power as traditional vacuum cleaners and much higher suction power than other robotic vacuum cleaners. It has a stereoscopic vision system and additional sensors for accurate localization, mapping, and path planning.

Figure 2 Visual impression of the Eagle

3.2.2 Creating a personality profile

In this case study, two rather distinct personality profiles were created by creative story writing to explore a broad design space in terms of product personality and behaviour for this type of product. Each personality profile consisted of a short backstory. Backstories are often used in theatre and reveal background information about past events that are relevant to a character and underlie the character's behaviour in the main play. The second part of the profile describes the key personality traits of the character in relation to its main purpose: cleaning. The first personality is called Ally, the playful elephant.

> *Ally was born a few years ago in a National Park in the South-East of Africa. In the first months Ally was sold to the owner of a zoo and transported to Europe. Life in the zoo was quite boring. Every day, people came over and watched Ally doing nothing. One day, Ally decided to break out and seek the adventure. After days of wandering, Ally ended up at your place. Ally is happy now, since Ally has a nice and warm place to live and a clear goal in its life. Ally wants to clean the floors and make all family members happy.*
>
> *Ally is extravert and playful. Ally likes to be on the foreground and is a true entertainer. Ally's animal friends in the zoo were very sad when Ally left, because they found Ally a very amicable and friendly elephant. Ally really feels like a companion and friend of the family. Ally is very strong and powerful, yet at the same time calm, soft and even sensitive. Ally is very cautious when moving through the room because Ally is afraid of damaging the furniture or other precious things. Because of this cautiousness, Ally is perhaps a bit slow and it takes Ally a while to finish the cleaning job. But Ally prefers to clean in a safe way rather than to be very fast. Ally's biggest fear is that one day, you get bored with Ally and throw Ally on the street.*

A rather different personality is Bart, the serious ant eater.

> *Bart was born a few years ago in Mexico. By accident, Bart ended up in a load of wood and was shipped to the harbour of Rotterdam. Bart was totally lost and wandered around for a few days. On a rainy Saturday, you found a sad Bart in your back garden. You offered Bart a place to live, for which Bart is very grateful. In return, Bart promises to the utmost to keep your house clean.*
>
> *Bart is very polite and conscientious. Bart takes the job serious and wants to be the best assistant you could wish. Bart works hard and doesn't want to be disturbed during the cleaning job. Bart is very precise and therefore has a tendency to take a long time for the cleaning. It is very important to Bart that you trust him and believe that he is able to clean the floor thoroughly and in a safe way. He does everything to show you what he is doing. Bart's biggest fear is that at a certain moment, you are not satisfied with the cleaning result and fire him.*

3.2.3 Expressing personality in behaviour

A theatre workshop was organized to explore the design space for realizing life-like and expressive behaviour for the robot. During the workshop, four actors from an improvisational theatre group acted out possible behaviours of the robot vacuum cleaner on the basis of the two personality profiles of Ally and Bart (see Figure 3). The workshop was organized to explicitly address the creative and artistic aspect of the design process for the robotic application. Acting out the behaviour of a robot captures implicit intuitions about personality that are otherwise difficult to express formally in written profiles or user requirements. This method has been successfully applied in movie and theatre acting for decades (Stanislavski & Hapgood, 1989). It is especially useful for emotional expressions, since acting provides unique access to emotions, due to the interrelated nature of emotion experience, emotion expression, and readiness for action (Trappl, Petta, & Payr, 2003).

Figure 3 Actors expressing robot behaviour

The moderator of the workshop presented a situation to the actors, for example: "You encounter an obstacle". Actors who had an idea how to act in this situation stepped forward and acted out the robot behaviour. The moderator ended the scene after the performance and asked the next actor to act out the robot behaviour and showed the expressions of the robot in the situation of interest. In another exercise, while one actor freely acted out some behaviours, a second actor had to give live commentary of what he or she was seeing. Some scenes were acted individually and others in groups. Over 200 scenes were recorded with the cameras. Video cards – printouts with a screenshot and short description of a recorded scene - were used to group, compare, and analyse the video material (Buur & Soendergaard, 2000). The clustered video cards with descriptions of the behaviour and example video clips were used in discussions with the project team and provided input to specify design rules for the expressive behaviour of the Eagle. Figure 4 shows an example of an observed actor's behaviour.

[Example: Scene 185] **Situation**: Robot enters a new room and starts 'mapping the environment'. **Expression**: Actor pretended to grab a camera and then looked to the left and the right, while making pictures of the room, accompanied by the sounds: *'Zzzooomm…Click. Zzzooomm…Click.'*

Figure 4 Example coding of an actor's performance.

3.2.4 Specify design rules

The previous step in the design process resulted in many ideas how to express the desired robot personality in its behaviour. The behaviour of the robot was specified in high level design rules for the key moments of the cleaning process: switching on, mapping the environment, regular cleaning, cleaning a dirty spot, and switching off (see Table 3). The video clips of the expressions of the actors were translated into expressions for the domestic robot. Since human expressions cannot be mapped one-on-one to expressions of the robot, the human expressions were abstracted before designing concrete robot expressions (see Figure 5). The expressions were sketched in a written scenario and visualized in an animated storyboard (see Figure 6). This scenario and storyboard were used to communicate the expressions within the project team. Although presentation of animated behaviour on paper is difficult, people inside the project team were able to give initial feedback on the cartoon-like drawings showing the robot behaviour. The final storyboard and accompanying design rules served as input for implementing the behaviour.

Table 3 High level design rules for Eagle

Moment	Design rule
Switching on	Should express it is active and preparing the cleaning run
Mapping environment	Should express it is creating a map of the room
Regular cleaning	Should express it is cautious and cleans in a structured way
Cleaning dirty spot	Should express it makes an extra effort to clean the spot
Switching off	Should not stop abruptly but silently move back to base station

Situation: Robot enters a new room and starts 'mapping the environment'. The actor visualized this by looking around and pretending to make pictures of the room. This was translated into a design rule for the robot: "If the robot enters a new room, then repetitively turn to the left and to the right ('looking around'), while flashing white lights ('camera flash light'), and making camera focus and click sounds ('picture taken')".

Figure 5 Example coding to translate an actor's performance to robot behaviour.

3.2.5 Implement behaviour

The storyboard on paper has some limitations in showing the design ideas, especially in expressive behaviour through light, sound, and motion. Behaviours in these modalities are hard to convey on paper. A more realistic visualization was needed to convey the designed robot behaviour (with movements, lights, and sound) and evaluate it with potential users. The scenario as presented in Figure 6 was implemented using the Open Platform for Personal Robotics (OPPR) software, developed in Philips Research (Breemen, Yan, & Meerbeek, 2005). This software tool can be used to design animated robot behaviour using prescribed animations or procedural animations.

A virtual 3D model of Eagle was created and integrated with the existing OPPR software. To create realistic scenarios, a 3D virtual model of a living room where Eagle could move in was added to the OPPR tool. Physics simulation was added to provide realistic behaviour. Figure 7 shows a screenshot of the tool that was used to animate the virtual Eagle. The implemented scenario resulted in a video clip of about 8 minutes showing the designed behaviours of the robot in various situations. In addition, five cleaning patterns were designed to find out how people perceive the different patterns (see Figure 8). Finally, two behaviours of Eagle cleaning under a table were implemented: one using a playful approach and the other a more serious and structured approach. The first pattern was designed to be structured, purely functional, and serious. The second pattern was designed to be more playful (less structured, head going around the table leg and look at canister).

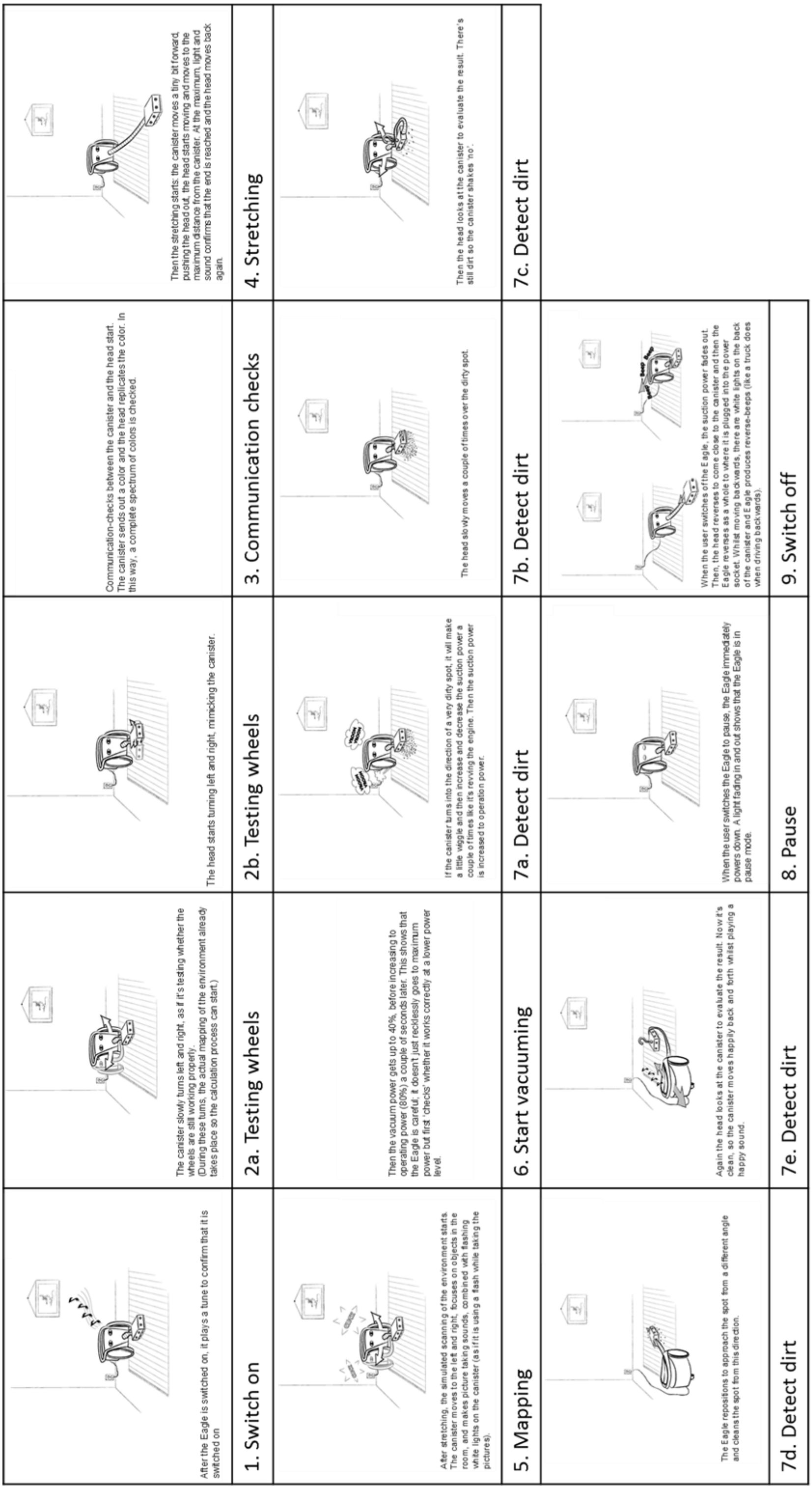


Figure 6 Storyboard depicting cleaning run of Eagle

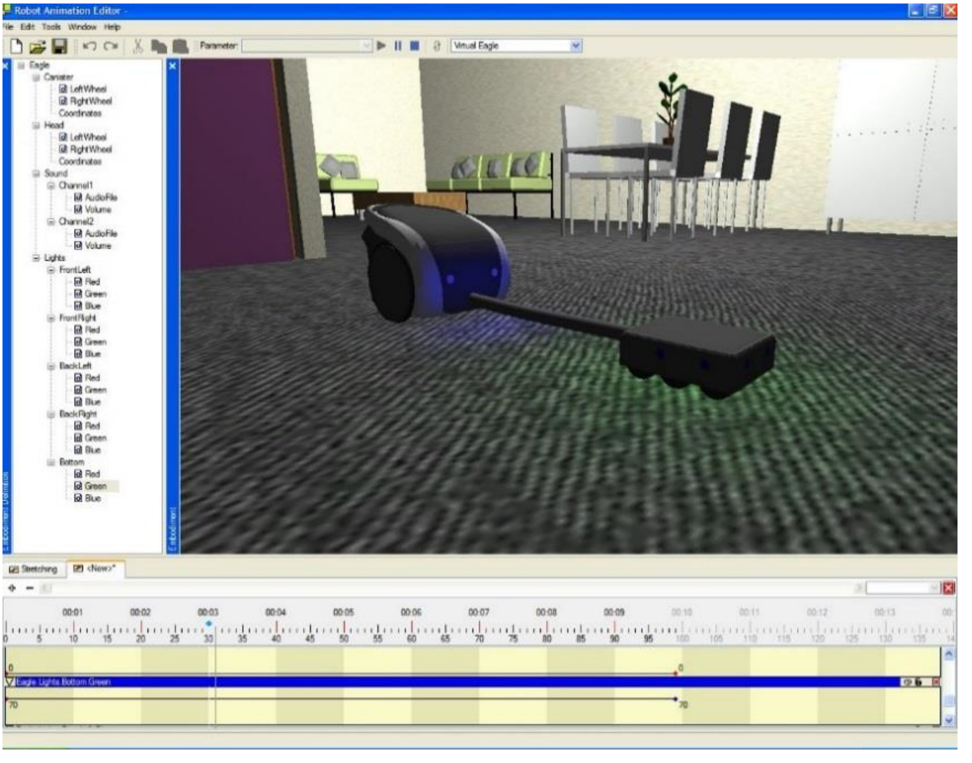


Figure 7 OPPR Animation Editor with Virtual Eagle

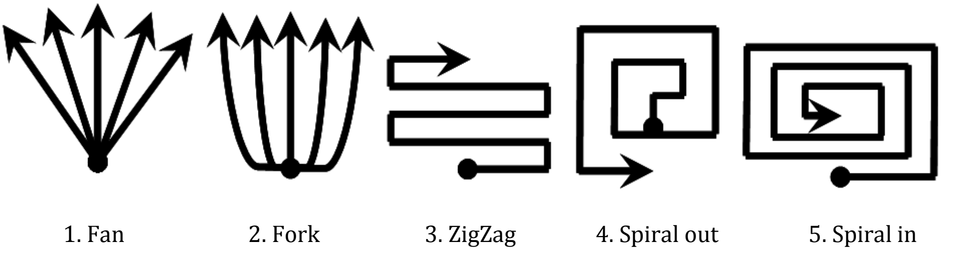


Figure 8 Schematic representation of cleaning patterns

3.2.6 Evaluate behaviour

3.2.6.1 Goal

The objective of this user test was to obtain user feedback on the behaviours implemented on the virtual Eagle (see section 3.2.5) as input for redesign and implementation of these behaviours on the physical Eagle. A think-out-loud protocol was used to understand what users think when they see the robot behaviours. How do people interpret the designed behaviours? What behaviours do people consider lifelike and why? Why is some behaviour preferred over other behaviour?

Table 4 Background information on the living situation of participants

Living situation	Single room app.	2 or more room app.	Single family dwelling	Bungalow
Participants	2	7	2	1
Size (m^2) living room (average)	21	61	100	200
Persons in household (average)	1	2.3	2.5	1
Persons with pets		1		

3.2.6.2 Method

In total, 12 participants (10 male) were invited to the Philips ExperienceLab (Loenen, Ruyter, & Teeven, 2006) for an individual session of about 1 hour. The average age of our participants was 29.6 years (min. 25, max. 42). Table 4 shows background information on the living situation of our participants. All were highly educated, open to using new technologies, and most used their current vacuum cleaner at least once every two weeks. Participants were welcomed and asked to sign an informed consent and fill out a demographic questionnaire. The experimenter explained the procedure of the experiment. After that, a semi-structured interview was conducted to find out more about the current cleaning practices of the participant. After the interview, a short introduction to the Eagle was given. While the 8-minute video clip of the virtual Eagle was shown on a projection screen, participants were asked to continuously describe what they saw, thought, and felt and why (think-out-loud protocol). What do you think the Eagle is doing or what is it trying to tell you? After the video of the cleaning run, participants filled out a questionnaire while verbally motivating their choices. Next, pairs of cleaning patterns were shown in video clips and participants were asked to compare them and indicate which one they prefer. The session was closed with a semi-structured interview with these questions:

1. What is your first impression of the vacuum cleaner you have seen?
2. What do you like about the vacuum cleaner?
3. What should be improved?
4. What do you think about its movements | lights | sounds?
5. Would you recommend the cleaner to a friend or relative? Why (not)?

3.2.6.3 Results

Video scenario

When the Eagle was switched on (step 1 of scenario), the first aspects people noticed were the sound and lights. While the Eagle performs the communication check (step 3), people explained the observed behaviour. '*The light is green, so he is probably happy. He thinks it is Christmas*', referring to the sounds and lights produced by Eagle. '*It is as if the big one is talking to the little one*'. Others did not understand what was happening: '*It looks funny, but it doesn't make sense*'. As the Eagle started mapping the room (step 5), participants noticed the photo flashes and camera sounds which made them understand that the mapping has started. '*I have no idea what it is doing now. Is it already cleaning…? Ah, it is taking pictures now. It is mapping the room.*'. But the analogy of taking pictures also caused some confusion, mainly for the participants with a more technical background: '*I thought it would work with ultrasound, so why does it make pictures?*' and '*The flashing is funny, but I'm not sure about the function. I think it would also be possible to use infrared.*'. Some participants were creative in motivating the picture taking: '*Maybe it is making pictures to be able to proof at a later stage the furniture was already damaged, so Philips won't get sued.*'. Some participants expressed that the mapping takes quite long: '*This is a moment when you think: let's go out of my home.*' and '*I would have already cleaned half of the room.*' and '*It takes really long to map the room. But next time, it will remember the room, right?*'. After the mapping, Eagle started vacuum cleaning (step 6). Some participants mentioned that it behaved differently than they expected: *'When I do it, I would start in the corner. So I would expect Eagle to start in the corner as well. But hey, if it does its job it's okay.*' and *'I would expect it to go to the corner first. That is at least what I would do. But I can't expect him to do what I want, of course.'*. The last parts of both statements are interesting and remarkable. The statement *'I can't expect him to do what I want'* might reveal that their relation with the robot vacuum cleaner is different from their relation with for example the television. It would be strange and probably unacceptable if a television behaved differently from what you order it to do (e.g. switch to channel 8 instead of channel 3). Apparently, this participant would allow the vacuum cleaner to have some autonomy and approach the cleaning in its own way, as long as it delivers a good result. Although most people understood that the red light indicated that Eagle was cleaning, the meaning was not clear for all people and caused some confusion: '*I don't know about the light. Perhaps something to detect the floor texture?*'. One person also doubted the usefulness of all the signalling towards the user: '*The question is whether you need all the signalling to the user. Probably, you will go away when it is cleaning.*'. During dirt detection (step 7), communication takes place between the canister and the head. Although most people do not fully understand what is happening, they all noticed that some communication was going on: '*It is really cute. I have no idea what they are talking about. He is talking to his nose.*' and '*This looks like teamwork. The cleaning unit tells the big guy that it is clean now. And the big guy give commands to the cleaning unit with the lights.*'. Finally, the Eagle drove back to the base station (step 9). People understood that the Eagle stopped cleaning: '*Apparently, it thought it was finished, so it went back to its starting position.*'. The analogy with a truck in reverse evoked a laugh with some participants: '*Hahaha. It is parking! This is a very cool one.*'.

Cleaning patterns

After the 8 minute scenario, participants watched several pairs of cleaning patterns of the Virtual Eagle and were asked to compare the patterns. Five cleaning patterns were compared; the first clip always showed pattern 1 (Fan) and the second either pattern 2 (Fork), pattern 3 (ZigZag), pattern 4 (Spiral out) or pattern 5 (Spiral in). Participants indicated their preference and explained why one pattern was preferred over the other. Table 5 presents an overview of participants' descriptions for the five patterns. Figure 9 shows the number of participants that preferred either the first or the second pattern per compared pair of patterns. It shows that most participants preferred the Fork pattern over the Fan pattern. Also, more people preferred the ZigZag over the Fan. Main reasons why the Fork was preferred over the Fan were:

1. it covers a bigger area
2. it looks more deliberate
3. it looks systematic and logic
4. it is a good mix of natural (human) and structured (machine)

The final pair of clips that participants compared showed two approaches for cleaning under a table, serious and playful. Figure 10 shows that the designed playfulness and seriousness were interpreted as such by most participants. It also indicates that the playful approach was more exciting to watch. However, most people preferred the robot with the serious pattern. Also, the robot with the serious pattern was understood better by the participants, people had more trust in it, and they thought the robot with the serious pattern would be able to best take over the cleaning job. One participant mentioned: '*Efficiency is for me the most important aspect to judge the patterns.*'

Table 5 Participants descriptions of cleaning patterns

Pattern	Participants descriptions
1. Fan	Human-like, Fan pattern, Classical man-like vacuuming, Not too careful, just back and forth, Natural, Nice & simple, Organic, Old-fashioned, Spider in the web
2. Fork	Systematic approach, 50/50 human/machine, Expected pattern, In clear-cut area with short movements, Square-like, In between efficient and old-fashioned, Reasonably simple, Sequential, Straight lines, Square area with fixed starting position, Organic, Quick
3. ZigZag	Engineering approach, Matrix, Close to my pattern, Zig-zag pattern, Machine-like, S-curves in a rectangular area, Efficient but boring, Robotic, Ordered
4. Spiral Out	Overkill, Not logical, Lots of short turns and movements, Spiral out, outgoing spiral, spiral outward, Efficient, Complicated pattern, Looks very "made", Playful, Ridiculous spiral, Repetitive, boring
5. Spiral In	Large inward spiral (square-spiral), Spiral in, inward square spiral, Complicated pattern, Machine-like, Robot-like, Linear, Playful, Lawn mowing style, Systematic

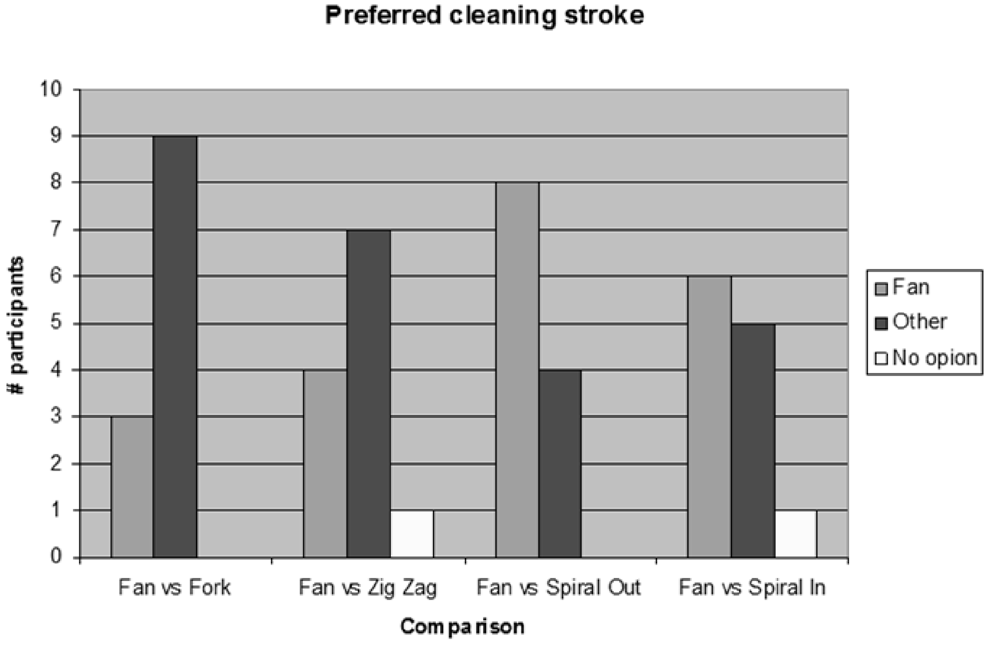


Figure 9 Participants preference after comparison of cleaning patterns

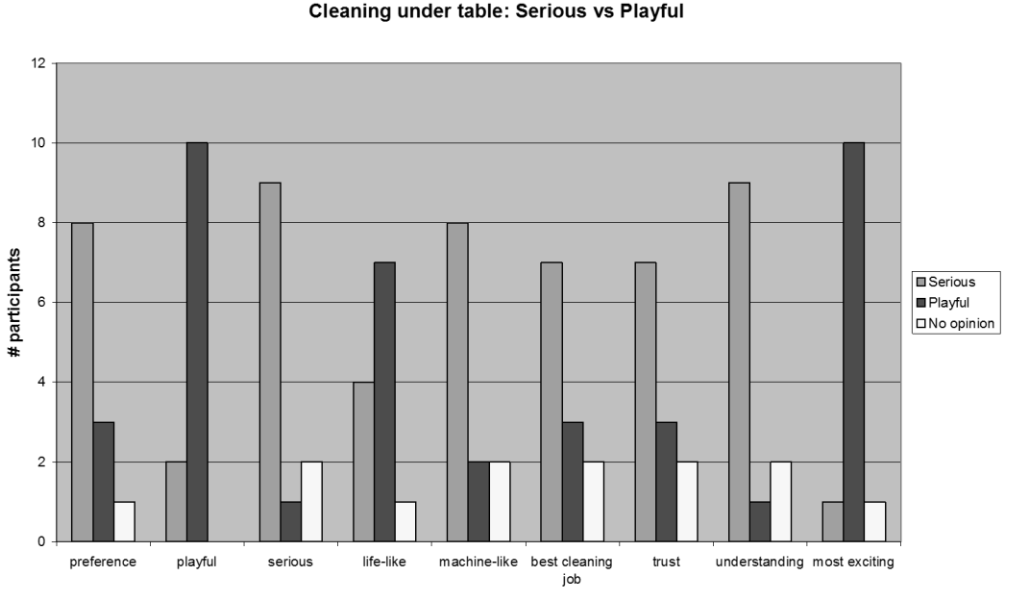


Figure 10 Comparison of a playful and a serious approach of cleaning under a table

3.2.7 Conclusion Case 1

Two distinct personality profiles were created for Eagle - a more serious and a more playful one – and used to inspire the creation of expressive behaviours for the robot in a variety of situations. Several concepts for expressive behaviours of Eagle were developed and qualitatively evaluated using a virtual representation. The results provide insights into how people perceive the expressive behaviours and the different cleaning patterns of the robot, which is valuable information for further design of expressive behaviour for robotic vacuum cleaners, as well as for the design of other intelligent systems. The designed expressions in motion, light, and sound were often interpreted in various ways by the participants. Participants could distinguish the serious and playful personality in the type of cleaning pattern. Although the robot with the playful approach was more interesting to watch, the robot with the more serious approach was generally preferred because the pattern was better understood, more trustworthy, and perceived to clean better.

3.3 Case 2: Falcon

3.3.1 Introducing Falcon

The second product concept to which the robot personality design process was applied is Falcon. In contrast to the Eagle robotic vacuum cleaner that consisted of two independent parts, the Falcon is a single unit robotic vacuum cleaner comparable to the Philips HomeRun as depicted in Figure 11.

Figure 11 Philips HomeRun

3.3.2 Creating a personality profile

To create the personality description for Falcon, a user-centred approach was taken. The most widely accepted personality model in psychology (Big-Five, see section 2.1.3) was used as an initial model for robot personality specifications. Many questionnaires for assessing human personality along the Big-Five dimensions are available, and these typically consist of a large number of items (Costa & McCrae, 2008; John & Srivastava, 1999; Saucier, 1994). For each dimension, four personality characteristics were selected (two positive and two negative) that were expected to be useful indicators for the desired robot personality, given the robotic vacuum cleaning application (see Table 6). The guiding principle for item selection was to cover a broad variety of relevant personality characteristics. Using more items was intentionally avoided, because it could lead to unacceptably long sessions with the participants of this study.

Fifteen participants (11 male, 4 female; age between 26-52 with average of 36) were recruited using several screening criteria so that they fit the target group of the product (i.e. they could be considered potential end-users of robotic vacuum cleaners). The personality items were presented to the participants on cards and they were asked to explain to the interviewer what the characteristics would mean for the behaviour of the robot. Next, they were asked to place the cards with personality characteristics on a large paper sheet to indicate how much this characteristic was desired in the behaviour of the robot (see Figure 12). The cards triggered rich feedback from the participants and provided valuable insights on what users might expect from the robotic vacuum cleaner. An example of the type of feedback that was generated using this approach is denoted in Figure 13.

For each personality item, a *desirability* score was calculated leading to the desired personality profile depicted in average scores on the five dimensions. Table 7 shows the fraction of participants that find a personality trait desirable for a robotic vacuum cleaner. The traits that are followed with a (-) are traits that score negatively on the personality dimension. For example, if one scores high on the trait 'calm' it contributes to a lower score for neuroticism. The results indicated that participants expect their robotic vacuum cleaner to be somewhat reserved and withdrawn, while at the same time energetic but not talkative. It should be cooperative and not bold. Furthermore, it should be efficient and systematic, but not careless. It should also not be easily discouraged or moody, but calm and relaxed. Finally, it should like routines but also be a bit curious and creative to learn and discover new things. The next section will present how participants expect these personality traits to be expressed in the behaviour of the robot.

Table 6 Selection of 20 personality items

Dimension	Items
Extraversion	Reserved, Talkative, Energetic, Withdrawn
Agreeableness	Polite, Bold, Distant, Cooperative
Conscientiousness	Systematic, Careless, Spontaneous, Efficient
Neuroticism	Relaxed, Calm, Easily discouraged, Moody
Openness	Creative, Superficial, Curious, Likes routines

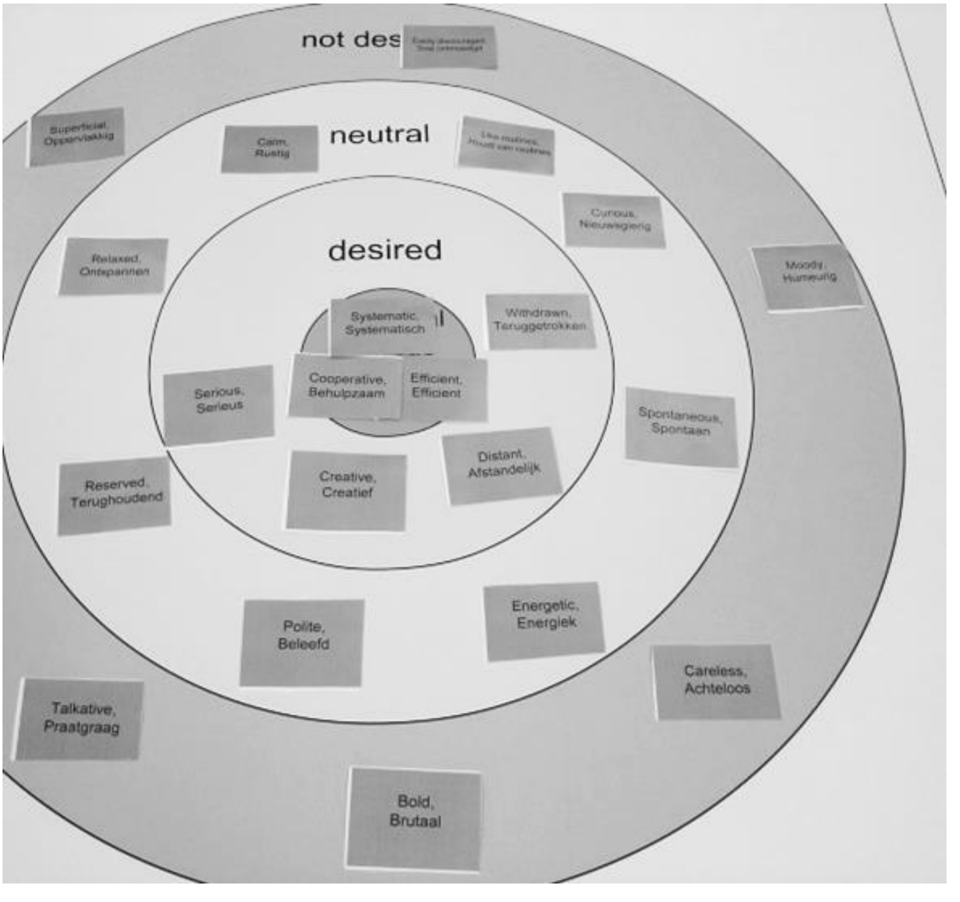


Figure 12 User-created personality profile

A participant was shown the card with the word 'polite' (agreeableness). She explained that this could mean that "when the robot wants to move in the same direction as you do, it will wait and let you go first. Yes, that is a desired behaviour. I put it close to the centre."

Figure 13 Example response of participant on the personality trait `polite'.

Table 7 Fraction of participants (N=15) finding personality trait desired for robotic cleaner

Personality dimension	Personality trait	Not desired	Neutral	Desired
Extraversion	Withdrawn (-)	13%	33%	54%
	Energetic	20%	20%	60%
	Talkative	93%	7%	0%
	Reserved (-)	7%	33%	60%
Agreeableness	Cooperative	0%	0%	100%
	Distant (-)	20%	40%	40%
	Bold (-)	93%	7%	0%
	Polite	13%	47%	40%
Conscientiousness	Efficient	0%	0%	100%
	Spontaneous (-)	33%	53%	13%
	Careless (-)	100%	0%	0%
	Systematic	0%	13%	87%
Neuroticism	Moody	80%	7%	14%
	Easily discouraged	87%	13%	0%
	Calm (-)	0%	13%	87%
	Relaxed (-)	7%	20%	73%
Openness to new experiences	Likes routines (-)	0%	27%	73%
	Curious	13%	47%	40%
	Superficial (-)	53%	27%	20%
	Creative	27%	20%	54%

3.3.3 Expressing personality in behaviour

The rationale participants provided for a personality trait to be desired or undesired provided more insight into the expected behaviour of the robotic vacuum cleaner. The concrete behaviour examples not only provided data on users' expectation about robot behaviour and personality, they also narrowed the design space for prototyping behaviours by giving concrete instances to implement a desired personality characteristic. Table 8 and Table 9 list examples of desired behaviour and undesired behaviour per personality trait that were mentioned by the participants.

Complementary to the user study on desired personality characteristics and behaviour, a workshop was held in which members of the project team discussed the desired personality for Falcon. Goal of the workshop was to, based on a discussion of the user study results, reach agreement on the desired personality profile of Falcon. To ensure that the full broadness of personality was discussed, the Big-Five theory of personality was used again as a theoretical framework. During the workshop, the desired behaviours for Falcon on the different personality dimensions were discussed and a conclusion was formulated which personality and behaviours should apply to the design of Falcon.

A descriptive personality profile was created based on the user study results and the expert workshop. This profile is a narrative description illustrating the personality of the robot and could be used in a similar way as personas (Pruitt & Grudin, 2003). Although personas are often used to describe users in the target group and describe them to a development team, the personality profile describes what (*who*) the product is. This profile provides a frame of reference for later stages in the development of the product behaviour.

> *The conscientious cleaning assistant Falcon was recently bought by Jason and Nicole, who didn't like cleaning floors and considered this too much of a hassle. Falcon was very happy to get out of the shop and find a new place to live. His main purpose in life is to clean the floor of its owners well and to make sure that they are pleased with him.*
>
> *Falcon is always very eager to clean the floor and finds cleaning a fun task. Since he doesn't want to disturb his owners, he is mostly working in the background. But of course, he is not too shy to call Jason's or Nicole's attention when it is necessary. He is not talkative, but clearly communicates the important things that Jason and Nicole want to know about his cleaning. He describes himself as a service-minded assistant who is very willing to help Jason and Nicole to making cleaning less of a hassle for them. Falcon is modest and regards his owners as his superior. He follows their instructions and doesn't start cleaning on his own initiative. Working efficiently is important for Falcon, because he wants to make sure that his superior is pleased with him. He is very aware of his duty and driven to achieve success. He wants to clean the floor well and within a reasonable amount of time, not wasting energy due to an inefficient way of working. Falcon is serious and well-organized. He likes to work systematically. He cleans the floor in a visually structured way. Falcon thinks before acting and is cautious. This becomes clear for example when you see Falcon dealing with your furniture. Falcon is definitely not lazy, but he is also not in a hurry or stressed. He is calm and not easily discouraged if he encounters problems. Falcon likes routines, but is also flexible enough to deviate from his plan or routine if needed. He easily adapts to new circumstances and is creative in finding solutions to problems that arise. Falcon is also curious to learn about its environment and about the wishes and desires of Jason and Nicole.*

Table 8 Examples of desired behaviour for robotic vacuum cleaner

Personality trait	Examples desired behaviour
Withdrawn (-)	It stands in the corner and does its job when needed. Just doing its work in the areas where no people are.
Energetic	It has to show that it is eager to clean. Fully charged, doing its things very well with power.
Talkative	It makes some noises and says hello.
Reserved (-)	If you are in the house, in a room, it could see you are there and then go and clean another room. Not part of the family, but knowing its place.
Cooperative	If you point to a dirty spot, it goes there and cleans it. If it enters a room where you are, it first cleans another room.
Distant (-)	Being unobtrusive, working in the background Just doing its job without arguing with or bothering you.
Bold (-)	n/a
Polite	If you are both going in the same direction, it will stop first. It will not come to an area where you are sitting on the couch.
Efficient	That it removes the dust successfully. Taking the shortest route.
Spontaneous (-)	If it is cleaning a room and it is more dirty than usual it spontaneously starts to clean more intensively.
Careless (-)	n/a
Systematic	It goes through the whole house according to a plan (not random) You always know what it will do it certain situations.
Moody	If it finds something it does not like, or gets stuck, then it gives sounds and lights asking for help.
Easily discouraged	It should not work 8 hours on one spot that doesn't get clean.
Calm (-)	Works silently. Move calmly through the room: not like a race car.
Relaxed (-)	No beeping, yelling, shouting user interface. Long strokes, slow turns.
Likes routines (-)	If a cleaning plan works well, it just keeps following it. Systematic and standard cleaning route.
Curious	Goes into areas it hasn't been before. In the first weeks, ask the user whether it has cleaned well.
Superficial (-)	Being very simple (i.e. having small number of features).
Creative	Trying several ways to go around obstacles.

Table 9 Examples of undesired behaviour for robotic vacuum cleaner

Personality trait	Examples undesired behaviour
Withdrawn (-)	It avoids you. Not going out cleaning and doing its job well.
Energetic	Gives the impression of urgency and rush.
Talkative	Indicate what it is doing all the time, and tell where it is going. That it communicates a lot.
Reserved (-)	Stay out of the room. If you call it, it will approach very slowly.
Cooperative	n/a
Distant (-)	Not giving feedback about what it is doing Not doing what you told him to do.
Bold (-)	It cleans under the legs of your visitors. It drives over the cat, or bumps against your feet.
Polite	That it would always greet you when it meets you. “Sorry to disturb you, but you better empty the bag in 5 days time.”
Efficient	n/a
Spontaneous (-)	That it starts working on its own initiative.
Careless (-)	Not going precisely around obstacles, but leaving parts uncovered. Bumping into obstacles and don’t mind hitting them.
Systematic	n/a
Moody	That it is stubborn and doesn’t feel like cleaning today.
Easily discouraged	Stops when it encounters an obstacle. Giving up quickly if something sticks to the ground.
Calm (-)	Trudging out of its base station.
Relaxed (-)	Staying lazy in its charging station.
Likes routines (-)	Does not adapt to changing circumstance, such as replacing furniture.
Curious	Driving into the garden and vacuum cleaning the lawn. Having own intentions and not acting according to my orders.
Superficial (-)	It quickly thinks: well this is clean enough.
Creative	Optimizing its cleaning route on the basis of previous runs, which could make it unpredictable.

3.3.4 Specify design rules

Based on the earlier findings, a set of 25 design rules for Falcon's behaviour was created. The design rules abstractly describe the desired personality and behaviour of Falcon. As with all design rules, these rules do not specify technical requirements for Falcon but rather provide guidance during the development of Falcon.

Falcon should:

1. work in the background and should not disturb the user
2. (only) make contact with users' when their attention is necessary
3. clean energetically but not like a race car
4. get its excitement and pleasure from the cleaning task
5. have fun in its work and keep trying to deliver the best cleaning result
6. trust users and their instructions
7. clearly communicate what the user wants to know and be honest when it was not able to clean a particular area
8. show eagerness to clean and always be ready to help the user
9. treat the user as its superior
10. be very capable of cleaning floors and be effective, meaning covering the whole floor and clean in corners and edges
11. clean in a visually structured way that is explainable by the user and gives the impression that no spot is missed
12. assure users the job is done whenever they want
13. be focused on completing its task, meaning persisting in difficult tasks and showing pride and satisfaction once the floor is cleaned
14. carefully plan how to go around obstacles and show the user it is thinking
15. not move too fast nor too slow through the room
16. make large cleaning movements
17. not be angry at the user for making a mess but accept it and clean it
18. not give up easily if problems occur and persist in finishing the job
19. be self-confident about its capabilities but also know its limitations
20. not react to its short-term urges and rewards but be a stable companion
21. not experience panic, confusion and helplessness when under pressure
22. not be driven by its own feelings, meaning ignoring its emotions if they are irrelevant to the user or to its functioning
23. prefer familiar basic actions and strategies and only try new things in case the familiar things do not work
24. limit its intelligence to the cleaning task
25. follow rules and accept users' authority, but also be open to re-examine existing behaviour and improve its performance

3.3.5 Implement behaviour

The design guidelines formulated in the previous section provided guidance for the development team of Falcon, for example in the implementation of the path planning software. In addition, some concrete robot behaviours in which Falcon's personality came to an expression were presented as short scenarios and evaluated with the same group of 15 potential end-users as described in section 3.3.2. Twelve scenarios were tested and the four highest rated scenarios are presented next.

Scenario 1: Falcon can be directed

> *Jason accidently throws the sugar bowl off the table and the floor is covered with sugar. He picks up the dirt pointer that came along with his Falcon and points towards the spot with sugar and presses the button on the pointer. 'Do you think he got it?', Jason says. As Jason presses the button, Falcon plays the 'instruction understood tune', and starts moving towards the selected spot. 'Oh yes, listen, it heard you, and it is coming to clean your mess Jason!', Nicole says with a smile. 'The salesman told us we can also instruct Falcon to clean a particular area, shall we try it out, and let it clean near the window where the leaves always lie?', Nicole asks. They agree to do so, so after Falcon has cleaned the spot, they use the pointer to select an area near their main window, where a lot of plants are standing.*

Scenario 2: Falcon knows and shows when floor is dirty

> *Jason and Nicole are watching Falcon clean the floor of their kitchen. They are particularly interested what it will do near Jason's chair, since he left a lot of bread crumbs on the floor. As Falcon detects this dirty spot, it shows the dirt detection light and goes over the spot repetitively, in order to make sure that every crumble is sucked up. 'He's is really putting extra effort underneath your chair Jason!', Nicole says with a smile. 'Yes, I see. The salesperson told me that Falcon also remembers the place where he found a lot of dirt. So next time, it will probably start under my chair, because it knows that I'm the dirty guy!'*

Scenario 3: Falcon is showing awareness of obstacles

> *As Falcon is cleaning, Jason and Nicole see it approaching one of their plants standing on the floor. As they watch it, Falcon slows down and gently moves around it. 'It's being extra careful with your favourite plant Nicole!', Jason teases. 'Well it is good to be careful, we don't want it to knock them over do we?', Nicole replies, 'or hit your precious ship models?' As they keep talking, Falcon approaches the glass salon table. When the couple turns to look at Falcon again, they just see it softly bumping against the glass side of the table. 'Hey, it just hit our glass table', Nicole says, 'it must not have seen it, just like you do sometimes Jason!' 'Jason, look, the poor thing hurt itself, and feels ashamed! See, it wiggles, and reduces the suction power a bit.', Nicole says. As they watch, Falcon resumes the vacuuming, and gently moves around the table.*

Scenario 4: Falcon shows you which stage it is in

> *In the afternoon, Nicole and Jason are sitting on their sofa browsing through holiday brochures, when they see Falcon driving by. 'Hey, it stopped vacuuming, why would that be?', Jason asks. 'Ha, ha, do you hear those beeps? It's just like a truck that is parking. It must be going back to its station now!' Jason laughs and watches Falcon return to its base station. 'Remember the salesman told us it always indicates which stage it is in?' After a while Jason goes to the kitchen to make some coffee, and sees the charging lights on Falcon blinking. 'Time for some energy for both of us, isn't it Falcon.', Jason says, and he starts making some coffee.*

Scenario 1 was implemented in an experience prototype called 'Point and clean' (Figure 15). A pointing device was developed that on a user press of the button beamed an infrared pattern on the floor as well as a small laser dot to provide users with feedback where they were pointing (see Figure 16). In addition, on a press of the button an RF signal was send to inform the robotic vacuum cleaner (with an RF receiver) that a command was sent by the user. The robot vacuum cleaner was equipped with a camera with infrared filter that would detect the location (x,y) of the LED pattern in the camera image (Figure 15). This location of the LED pattern in the 2D images was translated into (x,y,z) coordinates in the real world making use of the knowledge on camera height and angle. The robot provided subtle light and auditory feedback after receiving a user command with the pointer. A subtle green light and affirmative, ascending sound were presented in case the instruction was received well and could be executed. A subtle red light and negative, descending sound were presented if the command could not be executed, for example if the LED pattern was not detected in the camera's field of view. The light feedback was presented on the centre top part of the robot body.

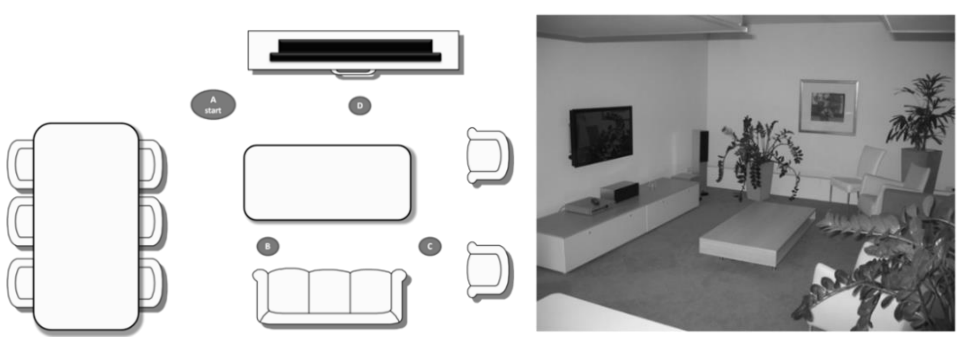


Figure 14 Experimental setting for evaluation of Point and Clean

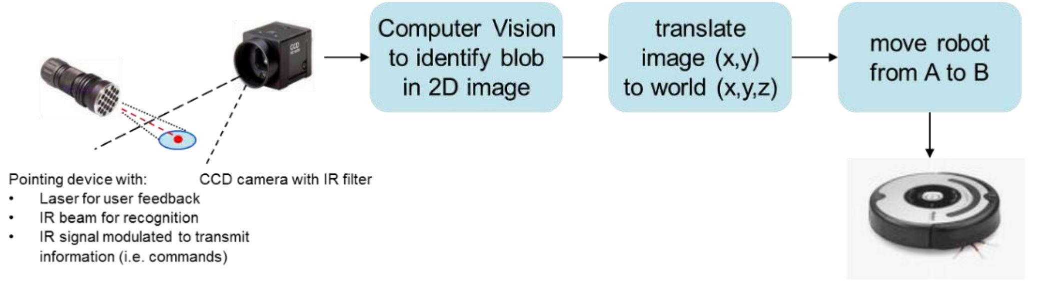


Figure 15 Schematic overview of Point and Clean prototype

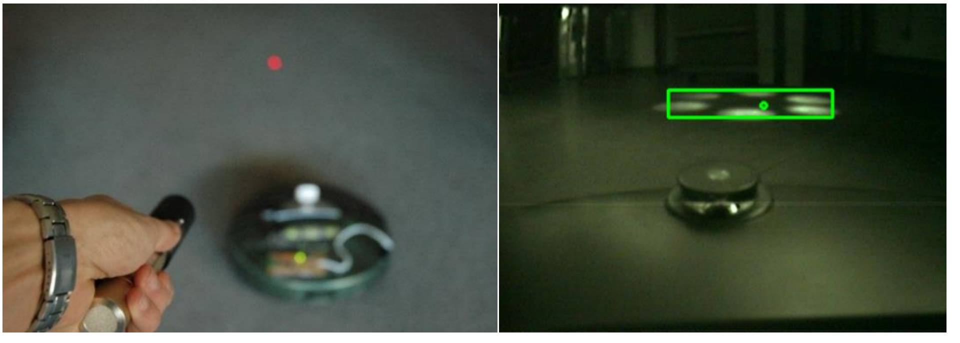


Figure 16 Pointing device to direct robotic vacuum cleaner to specific location (left) and Camera view from the robot detecting infrared spots on the floor (right)

Figure 17 Standard remote control (left) and IR dirt pointer (right)

3.3.6 Evaluate behaviour

3.3.6.1 Setting

The Point and Clean prototype was evaluated with 10 potential end-users (7 men, 3 women; between 26 and 43 years old, average 34) in a realistic living room environment in the ExperienceLab facility at Philips Research (Figure 14). Goal of the evaluation was twofold. First, to understand whether the implemented interaction paradigm of commanding the robot with a pointing gesture to clean a particular area would be appreciated by users and fit their expectations of how to interact with the robot. Second, to explore the effect of adding expressive behaviour (lights and sounds) on the users' experience of the interaction with the robot. All participants were asked to perform the task to guide the robotic vacuum cleaner from its starting position A to point B, C, and D.

Before performing the task, participants were asked to describe how they would naturally instruct the robot to move to these points. After this, they were asked to perform the task with the three interaction solutions that were provided:

1. Standard remote control of the robot vacuum cleaner

This remote control (Figure 17) offered a way to directly steer the robot: move forward, turn left, turn right (all from the robot's perspective).

2. IR Dirt pointer solution

This pointing device (Figure 17) emitted a laser light to provide the user with feedback where he was pointing at. Upon a press of a button, six highly collimated infrared LEDs emitted a pattern that could be recognized by the infrared camera mounted on the robotic vacuum cleaner.

3. IR Dirt pointer solution with expressive feedback.

This interaction solution was similar to number 2, but in version 3 the robotic vacuum cleaner would give expressive feedback to indicate to the user whether the pointing command was understood. If the robot detected the infrared pattern on the floor and it could execute this command, a subtle green light and affirmative, ascending sound were presented. A subtle red light and negative, descending sound were presented if the command could not be executed, for example if the robot received an RF signal that the user pressed the button on the pointing device but the LED pattern was not detected in the camera's field of view. The light feedback was presented on the centre top part of the robot body.

3.3.6.2 Procedure and measurements

The three interaction solutions were presented to the participants in a balanced order. After each interaction task, participants rated the user experience via a number of questionnaires. The attitude toward the presented solutions was measured using an adapted version of the short-form measure of attitudes (Ogertschnig & Heijden, 2004) consisting of 5 pragmatic items (useful, practical, functional, helpful, efficient) and 5 hedonic items (exciting, fun, amusing, thrilling, cheerful). All items were scored on a 5-point scale for their applicability to the presented interaction solution (not at all – extremely). Furthermore, the perceived level of control was measured with 8 items measuring perceived control (2 items) and self-efficacy (6 items) on a 7-point scale (Hinds, 1998). Ease of use was measured with 4 items on a 7-point scale (Venkatesh, 2000). Afterwards, participants were interviewed about their experience.

3.3.6.3 Results

Before interacting with the robotic vacuum cleaners, participants were asked what they would find the most natural way to instruct the robot to go from point A to point B. Most participants (7 out of 10) mentioned they would first call for the robot's attention (with a voice command) and then point to the destination to be cleaned. Although the Point and Clean solutions were closest to the ideal interaction method mentioned by participants prior to the experiment, after participants experienced the three interaction solutions the remote control solution was received more positively.

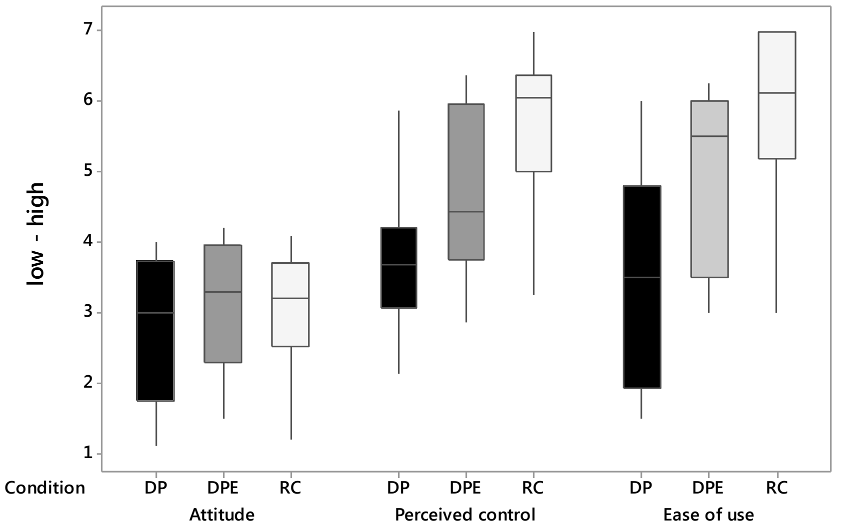
Initially, the remote control was confusing for many participants as the control actions are from the robots perspective. For example, if participants pressed the button to turn left, from their perspective it would look as if the robot turns right. But after this initial confusion, participant could control the robot and steer it to the destinations without real problems. One participant commented that it was rather time-consuming having to steer the robot directly to the destination.

The reactions on the dirt pointer concepts were mixed. Most people like the concept, but experienced some technical limitations that made them less positive about the dirt pointer. Particularly, the limited field of view of the robot was considered problematic as it required participants to point to several intermediate points before reaching the destination. Also, the accuracy of the solution was perceived to be low. The robot did not end up exactly at the spot that the participants indicated.

Figure 18 shows the boxplots for the scores on Attitude (pragmatic and hedonic items combined), Perceived control (control and self-efficacy items combined), and Ease of Use for the three tested interaction solutions. Given the limited sample size of only 10 participants, non-parametric statistics (Kruskal-Wallis) have been used to test for any significant differences (see Table 10). The attitude towards the system did not differ between the three conditions. However, there are significant differences between the three conditions on perceived control and ease of use. Participants perceived highest level of control in the remote control condition, followed by the dirt pointer with expressive feedback, and the dirt pointer without feedback. A similar result was found for the perceived ease of use. Pairwise comparison between the dirt pointer and the expressive version showed a tendency towards a higher perceived control ($p=0.103$) and perceived ease of use ($p=0.072$) for the expressive version.

Table 10 Mean scores on attitude, perceived control, and ease of use for 3 tested version and results of the statistical test

Measure	DP mean	DPE mean	RC mean	H-value	P-value
Attitude	2.8	3.1	3.0	0.42	0.809
Perceived control	4	4.7	5.7	10.15	0.006
Ease of use	3.6	4.9	5.9	9.26	0.010



Dirt pointer (DP), Dirt pointer with expressive feedback (DPE), and standard remote contol (RC)

Figure 18 Boxplots for attitude, perceived control, and ease of use for 3 tested interaction solutions

3.3.6.4 Discussion

Given the very small sample size for this user study, no strong conclusions can be made. However, some interesting observations were made that are relevant for the development of robotic vacuum cleaners. During the interview, people mentioned they want to give high-level instructions to the robotic vacuum cleaner, for example tell them which area to clean or instruct them when to start cleaning, rather than micro-level instructions such as controlling it directly to avoid obstacles or specify a detailed cleaning path. Instructing a robot to clean a dirty spot was recognized as a valuable feature, but people expect it to require almost no effort from the user. They expect to just call the robot's attention (for example with a voice command), and then instruct it where to clean by pointing to the destination. The expressive feedback from the robot was subtle and only 3 out of 10 participants indicated that they did not notice the difference between the dirt pointer and the dirt pointer with expressive feedback. Nevertheless, the expressive feedback seemed to increase the level of perceived control and ease of use, although not statistically significant.

3.3.7 Conclusions Case 2

In the Falcon case study, the Big Five theory of personality was used as a theoretical framework to investigate the desired personality for a robotic vacuum cleaner. Personality traits were used as triggers during interviews with potential end-users to help them express their desires with respect to the personality and behaviour of the robot. In line with the findings of the first case study, the results showed that people desired a serious, service-minded, and systematic cleaning assistant. The desired robot behaviour was captured in 25 design rules and 12 scenarios were created. These scenarios were textual description of the robot behaviour in various situations. The scenario that was most appreciated by the participants was developed into an experience prototype on a physical robot platform. A pointing device was developed that allowed users to point to a spot on the floor and instruct the robot to clean it ('Point and Clean'). Two versions of this prototype were evaluated with potential end-users: an expressive version that would give light and auditory feedback when receiving commands from the users and a non-expressive version that would execute the command without expressions in light or sound. Given the very small sample size for this user study, no strong conclusions can be made. However, some interesting observations were made. The expressive feedback from the robot was subtle and only 3 out of 10 participants indicated that they did notice the difference between the dirt pointer and the dirt pointer with expressive feedback. Nevertheless, the expressive feedback seemed to increase the level of perceived control and ease of use, although not statistically significant.

3.4 Case 3: Dusty

3.4.1 Introducing Dusty

A third and final product concept to which we applied the robot personality design process as described in Chapter 2 is Dusty. In contrast to previous cases of the Eagle and Falcon which were already existing robotic vacuum cleaner prototypes, the design process for Dusty started from scratch.

3.4.2 Creating a personality profile

In order to find out what robot vacuum cleaner personality people desire, a semi-structured interview was done with six Dutch participants, two women and four men, all fitting a target group of consumers who were likely to be early adopters of robot vacuum cleaners. Before the actual interview, participants were familiarized with the concept of a robot vacuum cleaner by presenting a visual overview of various existing robot vacuum cleaners. For the interview, thirty personality characteristics were selected from Big Five personality inventories (Costa & McCrae, 1992; Gosling, Rentfrow, & Swann, 2003). For each of the five dimensions, six characteristics that were considered relevant and interesting with respect to robot vacuuming cleaning were selected. Of these six characteristics, three have a positive connotation towards the dimension and the other three a negative. The characteristics were randomly presented on cards, and the participants were asked to evaluate the desirability. The personality inventories were used as a starting point, and the selected characteristics were cues for participants to talk about the desired robot personality and behaviour. It was found that people could quickly and easily assess the presented characteristics, and that they could make imaginative descriptions of their desired robot vacuum cleaner's personality. An overview of the selected characteristics is presented in Table 12. For each characteristic it is indicated which fraction of the participants considered the characteristic to be desired for a robotic vacuum cleaner.

Throughout the interviews, three recurring themes play a crucial role regarding the desired character of robotic vacuum cleaner. The first theme is 'goal-orientedness'. The participants desire a robotic vacuum cleaner that is concerned about vacuuming only and that behaves very much goal-directed, but at the same time respects the user and its environment. Participants do not articulate any need for possible entertainment qualities or any other functionality not concerned with its primary task. A second recurring theme is 'motivation'. The participants desire a highly motivated robotic vacuum cleaner. They want a product that persists in cleaning, but knows when it needs to withdraw. In case people make a mess, they do not want any negative response from the product and do not accept any reproach from the product. They do desire a helpful robotic vacuum cleaner that reacts in a positive, calm way. Finally, 'cooperativeness' is a recurring theme among participants. They desire a semi-autonomous robotic vacuum cleaner that is intelligent with respect to vacuum cleaning task. The participants expect the product to find its way, to localize dirt and dust, to recharge and possibly empty itself. However, they desire control over the robot when they feel they need to, for example when they see a dirty spot on the floor. Participants desired that the robot vacuum cleaner behaves in a calm way; it should express that it is in control of the situation. Furthermore, they wanted the robot vacuum cleaner to be cooperative. All participants desired an efficient robot vacuum cleaner that behaves in a systematic way. They wanted a robot that likes routines, as vacuuming is very much a routine job. Finally, the participants desired a polite robot cleaner.

In sum, the results show that people want a dedicated assistant. The robotic vacuum cleaner should express calmness, be at ease during cleaning and it should not give up too quickly on a certain cleaning task. It definitely should not be moody, on the contrary, it should communicate that it likes to clean and have a positive attitude towards cleaning. An introverted product personality is desired over an extraverted one. The product should be somewhat withdrawn, and not bother the user when this is not desired. The robot vacuum cleaner should definitely not be talkative. The product has to like the routine job of vacuuming. It also has to be intelligent with respect to the vacuum cleaning task. The product has to express friendliness. It should be polite. Furthermore, the robotic vacuum cleaner should be willing to cooperate with the user and be helpful as well. The product definitely needs to behave in a systematic way. It should not be careless. It also needs to have a serious attitude towards vacuuming (conscientiousness).

3.4.3 Expressing personality in behaviour

The results from the interviews as described in section 3.4.2 were used as a basis for designing the robot vacuum cleaner behaviour. A similar process as in the Eagle case study (see section 3.2.3) was followed to define the expressive behaviour of the robot. A role playing session was held in which 8 participants were asked to act out the robot behaviour in various situations. They were limited by expressing themselves through motion and sound (but no speech), as we decided to limit the expression of Dusty to the modalities of motion, light, and sound.

Motion, light, and sound are considered the three dominant modalities to the experience of the robotic vacuum cleaner. For each modality, a few dimensions were defined based on studies by Van Egmond and colleagues (Egmond, 2004; Klooster & Overbeeke, 2005). Motion is defined by its dimensions of spatiality, time and force. Sound by loudness, pitch and timbre. Light is defined by its temporal behaviour (see Table 11). The behaviour of the actors were analysed on these dimensions and used as inspiration for the design of the robot behaviour. For example, one of the actors who was asked to act like a robot vacuuming a dirty spot, started to clean that spot slowly thereby making repetitive, firm movements back and forth. These motion aspects of the behaviour were then described as taking place on a small plane, slow, regular and tensed. This description was then used for the further development of behaviour of the robot vacuum cleaner and visualization in a video prototype (see next sections).

Table 11 Modalities and dimensions of expression for Dusty

Modality	Dimension	Examples
Motion	Spatiality	Directions, paths and planes, big-small
	Time	Fast-slow, accelerating-decelerating
	Force	Tension-release, control-uncontrolled
Sound	Loudness	Intensity, high-low
	Pitch	Frequency, high-low
	Timbre	Tonal-noise
Light	Temporal	On-off, fast-slow, regular-irregular

Table 12 Fraction of participants finding personality trait desired or not for robotic vacuum cleaner (N=6)

Personality dimension	Personality trait	Not desired	Neutral	Desired
Extraversion	Withdrawn (-)	0%	17%	83%
	Energetic	17%	50%	33%
	Talkative	100%	0%	0%
	Reserved (-)	33%	17%	50%
	Extraverted	67%	33%	0%
	Introverted (-)	0%	17%	83%
Agreeableness	Cooperative	0%	17%	83%
	Distant (-)	33%	0%	67%
	Bold (-)	83%	0%	17%
	Polite	0%	17%	83%
	Friendly	0%	0%	100%
	Unkind (-)	83%	17%	0%
Conscientiousness	Efficient	0%	0%	100%
	Spontaneous (-)	17%	33%	50%
	Careless (-)	83%	17%	0%
	Systematic	0%	0%	100%
	Disorganized (-)	100%	0%	0%
	Serious	0%	17%	83%
Neuroticism	Moody	83%	17%	0%
	Easily discouraged	83%	17%	0%
	Calm (-)	0%	0%	100%
	Relaxed (-)	0%	33%	67%
	Jealous	50%	50%	0%
	Not easily upset (-)	0%	33%	67%
Openness to new experiences	Likes routines (-)	17%	0%	83%
	Curious	33%	33%	33%
	Superficial (-)	50%	17%	33%
	Creative	67%	0%	33%
	Imaginative	50%	33%	17%
	Unintelligent (-)	50%	33%	17%

3.4.4 Specify design rules

Two types of behaviour of the robotic vacuum cleaner are distinguished: default functional cleaning and expressive behaviour in response to a particular situation. For the design process of Dusty, the main interest lies in the second type of behaviours. Three categories of expressive behaviour were defined: responsive to user input (e.g. when switched on, switched off, instructed to clean a particular spot), expression of self-awareness (e.g. when needs to recharge, needs to empty dust bin, needs assistance in case it is stuck), and expression of context-awareness (e.g. when encountering a dirty spot, approaching an object, approaching a person). Table 13 shows example design rules for the expressions of Dusty in motion, sound, and light for 8 typical situations it might encounter. These expressions were based on analysis of the actors' expressions during the role playing session as described in section 3.4.3. For example, the behaviour of the actor when asked to express himself while encountering a dirty spot is now formalized into high level rules for expressions in motion, lights, and sound. The expressions were implemented in a video prototype and evaluated with potential end-users as described in the next sections.

3.4.5 Implement behaviour

The designed behaviour was presented with a video prototype. Video prototyping is a very suitable and cost effective way for studying human-robot interaction and leads to results that are comparable to those that could be obtained from live interactions with the robot (Dautenhahn, 2007; Walters & Syrdal, 2008). The five-minute video prototype depicted a robot vacuum cleaner that encounters a variety of situations in a home context (see Table 13). The robot vacuum cleaner in the video was represented by a neutral physical design (i.e. cardboard box), as in this study the focus was on the behaviour. Some elements, such as an on-off button, were added to the appearance of the robot vacuum cleaner, as these were thought to be essential for the expressive behaviour as shown in the video prototype. An iRobot Roomba robot vacuum cleaner was used as a test platform for the motion aspects of the behaviour. This Roomba was adapted to be manually controllable by means of a joystick through a Bluetooth connection. A microcontroller was used to control the light, which consists of six separate LEDs. The vacuuming sound of the robot vacuum cleaner was recorded from a conventional vacuum cleaner, whereas additional sounds were designed by using sound development software. See Figure 19 for an impression of the video prototype.

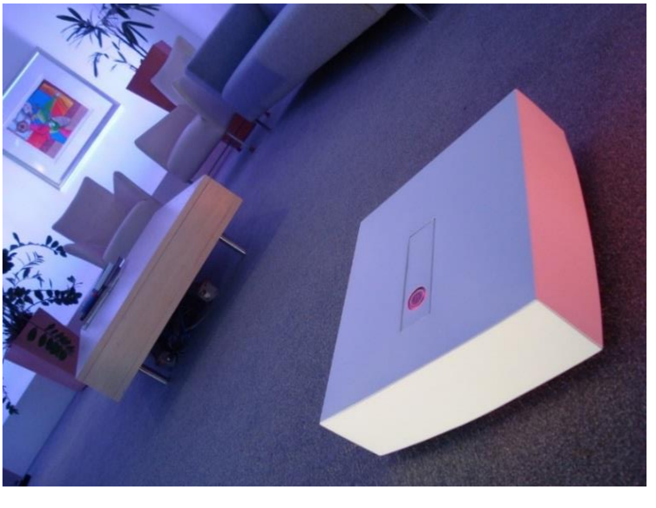


Figure 19 Impression of the Dusty video prototype

Table 13 Expressions of Dusty in motion, light, and sound in various situations

Situation	Motion	Sound	Light
Turns on.	Upward movement.	Staccato, high pitched beep upon switching on. Gradually increasing loudness of vacuuming sound.	Switch on.
Turn off.	Moves back to its starting position. Slows down and stops. Followed by a downward movement.	Vacuuming sound decreases and stops. Followed by a sound, decreasing in loudness.	Turns off
Commanded to clean a spot.	First small movement in opposite direction, then accelerate towards spot.	Two staccato, high pitched beeps.	Quick flashes.
In need of energy and recharges.	Slows down and stops for a moment. Moves slowly toward recharging point. Moves upward while recharging and downward after having recharged.	From high-to-low pitched sound. And a low-to-high pitched sound upon having recharged. No vacuuming sound.	Keeps on flashing, until it is recharged
Cleaning a dirty spot.	Slows down upon approach and stops for a moment. Followed by a slow, repetitive back and forth motion	High-to-low pitched upon approach. Increasingly loud vacuuming sound. Low-to-high pitched upon leaving.	Flashes upon approach.
Approaches a person, but decides to withdraw.	Slows down upon approach and stops for a moment. Leaves slowly in backward direction.	High-to-low pitched upon approach. Decreased vacuuming sound. Low-to-high pitched upon leaving.	Flashes upon notice.
Approaches an object.	Slows down upon approach and stops for a moment. Moves (cleans) around it.	From high-to-low pitched sound upon approach. Low-to-high pitched sound upon leaving.	Flashes upon notice.

3.4.6 Evaluate behaviour

The video prototype was evaluated with 15 potential end-users of a robotic vacuum cleaner (7 male and 8 female) using a think-out-loud protocol. Participants verbalized their thoughts while watching the video and were asked to share their overall impression afterwards. A questionnaire was used to assess to what extent each of the 30 personality characteristics that were used to define the desirable personality profile (see Table 12) applied to the robotic vacuum cleaner in the video (on a 5 point scale ranging from strongly disagree to strongly agree). All participants completed this task individually, after having seen the full video prototype. Participants were also asked to describe the behaviour of the robot for the various situations (see Table 13) in their own words to assess whether the expressions were perceived as intended by the designer. Subsequently, the descriptions of the situations were provided and participants were asked to match each description to a video fragment showing a robot behaviour.

When the participants were asked for their overall impression of the robot vacuum cleaner behaviour after seeing the video prototype, they described it by using personality characteristics such as calm (3), boring (2), careful (2), and systematic (2). Signs of anthropomorphism and personality attribution were observed throughout the evaluations. One participant explicitly mentioned that the robot vacuum cleaner has a character. Fourteen participants assigned a gender to the robot vacuum cleaner - when talking about it, they frequently referred to it as 'he' or 'him'. Only one participant consistently used 'the robot vacuum cleaner' or 'it'. Participants mentioned that the robot vacuum cleaner is alive (3), and like a domestic animal or a dog (3), or even like an infant (1).

The results with respect to the task of rating the personality characteristics indicate that the perceived personality matches with the intended product personality: calm, cooperative, efficient, likes routines, and systematic (the most desired characteristics as can be seen in Table 12). The participants were less in agreement on how efficient and polite they perceived the robot vacuum cleaner, although still the majority of participants agreed or strongly agreed that they perceived the robot as efficient (8/15 participants) and polite (9/15 participants). Table 14 provides an overview of the results for these six personality characteristics with the participant ratings, the mean rating and standard deviation.

Based on participants' descriptions of the situations that were shown in the video, it can be concluded that the situations were generally well recognized. Table 15 shows the situations the robot encountered and the percentage of participants that correctly recognized the situation. Most of the situations were well recognized, except the situation of the robot approaching a person but deciding to withdraw. Based on the participants' remarks, the most likely explanation causing the confusion was not the expression itself, but the way the video was edited (i.e. it suggested the robot was waiting for something). It should be noted that the videos obviously did not only show the expressions in motion, light, and sound, but also something about the context of the situation (e.g. some dirt on the floor). These contextual cues are also expected to help in recognition of the situations.

Table 14 Recognition of personality traits for Dusty

Personality trait	1 (Strongly disagree)	2	3	4	5 (Strongly agree)	Mean	SD
Calm	0	1	2	10	2	3.9	0.7
Cooperative	0	2	1	10	2	3.8	0.9
Efficient	0	2	5	4	4	3.7	1.0
Likes routines	0	1	2	4	8	4.3	1.0
Polite	0	2	4	7	2	3.6	0.9
Systematic	0	0	3	4	8	4.3	0.8

Table 15 Recognition of situations that robot encountered

Situation	Participants recognized situation (N=15)
Turns on.	15 (100%)
Turn off.	15 (100%)
Commanded to clean a spot.	13 (87%)
In need of energy and recharges.	14 (93%)
Cleaning a dirty spot.	14 (93%)
Approaches a person, but decides to withdraw.	4 (27%)
Approaches an object.	14 (93%)

3.4.7 Conclusions Case 3

As in case study 2, a selection of traits from the Big Five theory of personality was used to trigger potential users to express their desires with respect to the personality and behaviour of a robotic vacuum cleaner. The results for Dusty were consistent with the findings for Falcon: participants indicated to prefer a dedicated, goal-oriented, and cooperative cleaning assistant. This desired personality profile and behaviour was translated into expressions in motion, light and sound. A video prototype was created and evaluated using a think-out-loud protocol and questionnaires. The results showed that the perceived robot personality matched to a large extent the personality as intended by the designer. Furthermore, the expressions helped in interpreting the robot behaviour in various situations.

3.5 Conclusion and Discussion

The proposed process to design the personality and behaviour of a domestic robot (Chapter 2) was applied to three robot vacuum cleaner case studies (Chapter 3). The user-centred approach was followed to explore what kind of personality people would like a robot to have. Based on this user knowledge, an artistic perspective was taken to identify expressions and behaviour of a robot with a particular personality. A more technological perspective guided the translation of expressions and behaviours into concrete and implementable solutions for a particular robot embodiment, taking into account its requirements and constraints.

The three cases showed it is possible to design robotic vacuum cleaners that are perceived to have a personality that comes to expression in its behaviour, more specifically with motion, lights, and sounds. People were rather consistent in the type of personality and behaviour they expect from a robotic vacuum cleaner. The results for Falcon and Dusty on desired and undesired personality characteristics have been combined into Figure 20. The desirability scores have been calculated by averaging the desirability scores (-1 = not desired, 0 = neutral, 1 = desired) of each individual item on the five personality dimensions. The results show that people prefer a robot vacuum cleaner that has a somewhat introvert, agreeable, conscientious, and emotionally stable (non-neurotic) personality. Our studies provide first indications that the personality and expressive behaviour are recognized by users and help them to understand the robot and increase feelings of being in control and perceived ease of use.

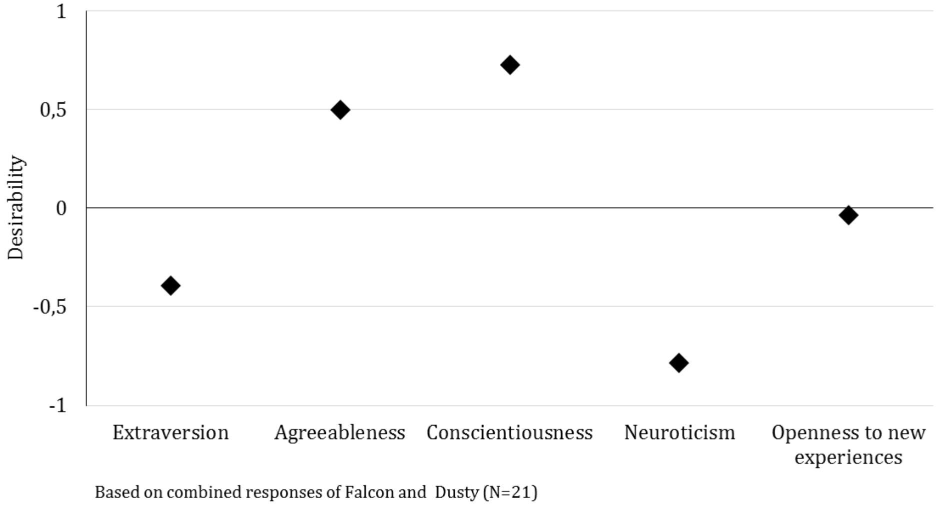


Figure 20 Desired personality profile for robotic vacuum cleaner

The remainder of this section summarizes the main lessons learned from applying this process to the design of personality and behaviour for the three robotic vacuum cleaners.

It was uncertain whether people would be able to make judgments or express their preferences on the basis of an imagined personality of a robot. However, from their rich responses in all three case studies it could be concluded that participants were able to relate personality characteristics of the Big Five model to the robot's behaviour. People seemed to have little difficulty explaining what a personality characteristic would mean for the robot behaviour and whether they would like this or not. However, a more systematic and objective selection procedure of personality items would be advisable. Ideally, a scale to describe robot or product personality would be validated in multiple case studies. It has to be noted that the described approach assumes that the application context for the autonomous system is known. This is because the task or role of the system is likely to have a large effect on the personality preference of users. For example, a surveillance robot is expected to have a different personality than a robot that plays games with children.

The theatre workshop was guided by an artistic approach to explore the design space and realize certain personality characteristics. It proved useful in inspiring the design of robot behaviour. However, it was challenging for the invited actors, who were used to expressing themselves verbally and via interactions with the audience, to use mainly body movements and abstract sounds. For this purpose, it might be more desirable to use dancers or mime actors. Another challenge was that the anatomy of the human actors is rather different from the anatomy of the envisioned domestic service robot. Therefore, it is difficult to map expressions of the actors directly onto the robot. However, movement patterns could be translated into concrete expressions for the robot by abstracting the expression of the actor and coding the essential characteristics of his movement. It might be worthwhile however, to explore other methods of inspiring the design of expressive behaviour, for example by tapping into the expertise and skills of puppeteers or animators.

Several ways to implement and evaluate the robot behaviour were used in the three case studies. In the Eagle case, 3D visualization was used to gather qualitative feedback from the user in an early design phase. From the feedback on the simulations it could be concluded that the participants were able to imagine the behaviour on a physical embodiment, despite the perceptual differences of observing a physical robot or a robot on a screen. Similarly, the video prototype that was used to evaluate the behaviour of Dusty proved to be effective to obtain rich qualitative feedback in early phases of a design process. The qualitative study using a think-out-loud protocol at this early stage of the product development is preferred over quantitative methods, because the protocol provides in-depth information about how participants perceive the robot behaviour. It allowed exploring participants' first impressions of specific robot behaviour rather than evaluating the overall perception of the robot behaviour at the end of a test.

Nevertheless, the use of a virtual representation of the robot or videos for evaluation has some limitations. For example, simulation of the (physical) interaction between a user and the robot is not possible. The robot and the user are not physically in the same room, missing the feeling of co-presence. For the second case, a physical implementation was made given the importance of the interaction between user and robot and co-presence in the Point-and-Clean scenario.

Future research could improve the process and investigate its applicability in a broader range of automated systems. Furthermore, data of more applications of this process are required for its validation and to benchmark it against existing product design processes.

4 Influence of robot personality on user control

While chapter 3 focused on robotic vacuum cleaner applications, this chapter describes the design and evaluation of a home dialogue system with the conversational robot named iCat: an expressive robotic interface platform for studying human-robot interaction. An application was developed that helps users to find a TV-programme that fits their interests. Two studies were conducted to investigate what personality users prefer for the robotic TV-assistant, what level of control they prefer (i.e. how autonomous the robot should behave), and how personality and the level of control relate to each other. The first study demonstrated that it is possible to create convincing personalities of the TV-assistant by applying various social cues. The results of the second study demonstrated an interaction between the effects of personality and level of control on user preferences. Overall, the most preferred combination was an extravert and friendly personality with low user control. Additionally, it was found that perceived level of control was influenced by the robot's personality. This suggests that the robot's personality can be used as a means to increase the amount of control that users perceive.

This chapter is based on the following publication:

Meerbeek, B. W., Hoonhout, J. H., Bingley, P., & Terken, J. J. (2008). The influence of robot personality on perceived and preferred level of user control. *Interaction Studies, 9*(2), 204-229.

4.1 Introduction

As described in Chapter 2 and Chapter 3, robots are entering our homes. Due to the increasing number of domestic robots, appropriate design of the interaction between humans and robots is an important research topic. In line with this development, Philips Research developed the "iCat" (Figure 21), which serves as a platform for studying human-robot interaction (Breemen et al., 2005). The iCat is designed with anthropomorphic features including eyes, facial expressions, body movements, and a human voice.

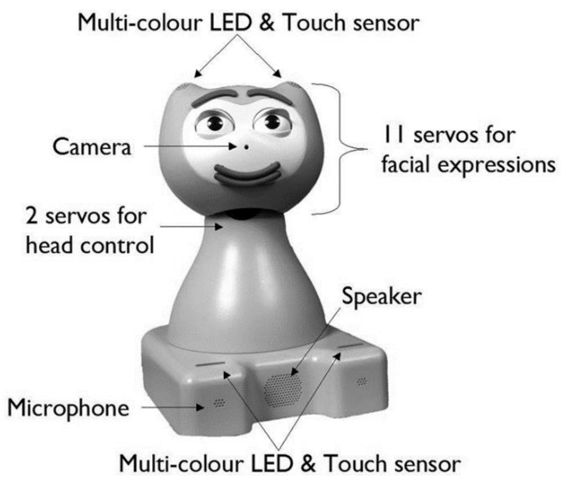


Figure 21 The iCat platform for studying human-robot interaction

The iCat was developed in line with the vision of Ambient Intelligence, in which technology will be embedded into the environment and will be able to recognize users and their situational context (Aarts & Marzano, 2003). According to this vision, technology will move to the background and intelligent systems will take tedious tasks out of the hands of humans, working relatively autonomously. This raises the issue of control. The study described in this chapter focuses on these two aspects: what kind of personality should a robot have, and how should the control over the interaction be distributed between the user and a robot. While chapter 3 focuses on robotic vacuum cleaners, the study in this chapter focuses on the application of the home dialogue system iCat as TV-assistant.

4.1.1 Personality and control

As mentioned in Chapter 1, the level of automation affects the level of actual control that is available to the human. An important question in field of Human-Robot Interaction is how much control the user wants or is willing to hand over to the robot (Hinds, 1998; Norman, 2001; Shneiderman & Maes, 1997). An advantage of a high degree of user control is the possibility of incremental action with continuous feedback. On the other hand, intelligent systems or robots can relieve the user from some of the attention and cognitive load traditionally involved in the interaction with large quantities of information. However, this relief comes at the cost of diminished control for the user. So, a relevant question is how much control the user is prepared to give up for reducing the (cognitive) load of the interaction.

The model of Parasuraman and colleagues (see Table 1) shows different levels of automation with higher levels representing increased autonomy of a machine over human action. Lower levels of autonomy correspond more to a master slave relation between user and system, while higher levels of autonomy correspond more to a partner relationship between user and system; in the latter case, the system can act autonomously on behalf of the user or initiate a dialogue to negotiate available options, while the user still has the opportunity to initiate a dialogue himself. As is evident from these observations, different levels of control affect the interaction style or dialogue strategy.

A high user control dialogue strategy (thus low system autonomy) requires users to take the initiative by giving short commands in order to trigger an action of the system. This user-driven interaction style is often called command and control. An example of such a user-driven dialogue is the command and control application that Microsoft offers for its operating systems, allowing users to control their personal computers with spoken commands. Such high user control dialogue strategies are usually more suited for experienced users. Under a high system control dialogue strategy the system initiates a dialogue and follows a scheme of questions with a limited set of permissible answers (typically "yes" or "no"). System-driven dialogues are typically used in automated call centres, in which the human uses a telephone keypad or speech to make a series of menu selections. High system control dialogue strategies are usually more suited for novice and incidental users. Although current speech-based applications often follow one of the strategies mentioned above, there are various levels of mixed-initiative dialogue strategies (Allen, Ferguson, & Stent, 2001). Key principle behind mixed-initiative dialogues is to enable a flexible interaction strategy suiting both novice and experienced users, and enabling each agent in the interaction to perform the task it can do best.

The concept of personality and the five personality dimensions of the Big Five theory have been explained in more detail in section 2.1.3, as well as how personality can be used in the design of robotic applications (section 2.3). In chapter 3, we focused on robotic vacuum cleaners that expressed personality through their movement patterns, lights, and sound. The scope of the study presented in this chapter focuses on conveying personality with facial expressions, head and neck motion, linguistic style, and speech for which the iCat is a very suitable research platform. We wanted to investigate whether it is possible to create recognizable synthetic personalities on iCat using these expressive means. If we can create personalities for iCat, the question that logically follows is what kind of personality the robot should have. While in chapter 3, we focused on a functional task of vacuum cleaning, this study addresses the question what type of personality users prefer in interactions with the iCat in the context of an entertainment-oriented TV recommender application (see section 4.1.2). Should the robot be extravert and assertive or maybe more introvert and submissive? Should it make the impression of being serious and hardworking, or should it be playful and spontaneous?

In addition to the questions on personality, this study addresses the question whether users prefer a high user control interaction style or a high system control interaction style. In the first situation, the user initiates the dialogue by giving commands to the system. The system can respond by performing the requested action or starting a sub dialogue. In the second situation, the system initiates the dialogue and the user responds by answering the questions in constrained natural language. In the remainder of this chapter, *high user control* will be used to refer to the first and *low user control* to refer to the latter.

Extrapolating from observations of interaction between humans, it can be expected that the level of control that is available to users should be consistent with the personality characteristics of the robot. If a user is in control and commands the robot what to do, a somewhat submissive personality might be preferred. Contrary, a more assertive personality might be more suitable if the robot is in control. Therefore, this study also addresses the question of what is the most preferable combination of personality and level of control for iCat as a TV-assistant.

4.1.2 Application context

The iCat is a research platform to investigate what it would mean if a personal robot is used in the home and engages in social interactions with its users. One can think of many potential application scenarios for these domestic robots, ranging from e.g. a personal assistant who can help with incoming messages and calendar appointments to a fitness coach who can provide advice on healthy diet choices. Prior to this study, 24 application scenarios for home dialogue systems were presented to participants and evaluated in an interview about the benefits and drawbacks of each scenario (Diederiks, Hoonhout, & Bingley, 2005). Since the TV-assistant scenario was one of the most appreciated, it was decided to build a prototype around this scenario. The goal of the TV-assistant is to help users find an interesting TV-programme. It informs users about programme details, recommends programmes based on their profiles or a genre that they specify and reminds them about their favourite programmes.

In this chapter, two studies are described. Study 1 was conducted to find out whether users were able to identify the personalities of the robotic TV-assistant as intended by the designer. In study 2, user preferences for control, personality, and the combination of control and personality were investigated.

4.2 Study 1: Perception of robot personality

4.2.1 Research question

The first study was conducted to find out whether it is possible to convey personalities of iCat as a TV-assistant to the user. Do people recognize the personalities that were intended by the designer?

4.2.2 Method

Two personalities (Catherine and Lizzy) were defined by choosing personality traits from three personality dimensions: extraversion, agreeableness, and conscientiousness – which we considered most relevant given the social and application context (see Table 16). Both personalities were designed to be similar and neutral on the openness and the neuroticism dimension. Female names were chosen because iCat is mostly perceived as female. The selection of traits was determined based on previous work (Verhaegh, 2004) and a discussion in the project team. It was agreed that the personalities should fit the application context and should not be too extreme. Both personalities should be able to function as a useful TV-assistant. Although it might be possible to convey a very neurotic or unfriendly personality on a robot, it was not considered as a serious option for a TV-assistant. Furthermore, it was decided that one personality should not be definitely "better" than the other (i.e. more likeable). iCat was available in two colours (intense yellow and olive green). Based on previous research on colours and human associations (Mahnke, 1996), it was decided to use the more intense yellow for the extravert Lizzy and the olive green for Catherine. In this way, the chosen colour matched with the personality traits.

Design guidelines for mapping the personality traits in Table 16 onto observable behaviour were derived from literature on the expression of personality (Ball & Breese, 2000; Breazeal, 2004; Cahn, 1990; Canamero & Fredslund, 2000; Ekman, 1993; Fong et al., 2003; Gallaher, 1992; Gill & Oberlander, 2002; Heylen, Es, Nijholt, & Dijk, 2002; Krahmer, Buuren, Ruttkay, & Wesselink, 2003; Murray & Arnott, 1993; Nagao & Takeuchi, 1994; Nass & Brave, 2005; Nass & Lee, 2000; Pelachaud & Poggi, 2002; Schröder, 2004; Severinson-Eklundh, Green, & Hüttenrauch, 2003).

Table 17 and Table 18 show the personality dimensions in the first column and the four personality cues that could be changed in the top row. Each cell describes the "settings" of that specific personality cue to achieve the desired changes on a personality dimension. It should be noted that these tables are not a complete description of how to establish personalities in a domestic robot, but it provides heuristics and guidance when designing the behaviour of a robot personality taking into account the limitations of iCat.

Table 16 Personality traits of Catherine and Lizzy

Personality dimension	Catherine	Lizzy
Extraversion	Somewhat introvert Modest Somewhat shy Expectantly	Extravert Talkative Enthusiastic Takes the initiative
Agreeableness	Polite Distant	Assistantly Empathic Warm-hearted Amicable Jovial
Conscientiousness	Formal Orderly Serious Careful	Impulsive Somewhat careless Light-hearted

Table 17 Guidelines Catherine (somewhat introvert, polite, and conscientious)

Personality dimension	Head and neck motion	Facial expressions	Speech	Linguistic style
Extraversion	Slower and less head movements Posture that minimizes size (head to chest)	Eyes move away from user No eyebrow movement Not expressive Eyes not wide open	Pitch mean low Pitch range low Speech rate slow Volume soft	Give suggestions to user Use formal words More negations
Agreeableness	Head a bit down	(Limited) smile	Pleasant voice	Polite language
Conscientiousness	Reserved nod	Frowning Thinking	Pitch mean low	Limited talking (no non-sense talk) Carefully formulated sentences Use passive voice Structured presentation of information

Table 18 Guidelines Lizzy (extravert, friendly, and somewhat careless)

Personality dimension	Head and neck motion	Facial expressions	Speech	Linguistic style
Extraversion	Faster and more head turning Faster and more head nodding Playful moves	Eyebrow movements that coincide with accented words Eyes frequently fixed on user while talking	Pitch mean high Pitch range high Speech rate fast Volume loud	Give commands to user (in a friendly way) Make jokes More present tense verbs Use more words Highly expressive language
Agreeableness	Head up	Smile Eyes wide open Brows upwards	Pleasant voice	Informal language Use active voice
Conscientiousness	Head turns away during conversation Sudden moves	Many brow movements (at “random”)	Speech rate fast	Chitchat Varied presentation of information

Two existing Text-to-Speech (TTS) engines were used for the voices of the characters: PTTS version 5.40 from Philips and RealSpeak Solo version 4 from Scansoft. The synthetic output of the PTTS engine was changed on four correlates compared to the original output, to make the voices fit the personalities. Catherine’s voice was kept more neutral to make it sound more formal, serious, polite, distant, and introvert. The voice of Lizzy was made a bit higher, faster, louder, and more varied to make it sound more enthusiastic, friendly, and extravert. The synthetic output of the RealSpeak engine was not manipulated. Based on a personal auditory judgement, the two Scansoft voices were selected that were assumed to fit best to the character descriptions of Lizzy (voice “Karen”) and Catherine (voice “Emily”).

4.2.3 Procedure and measurements

The first study took place in the living room of the ExperienceLab facility at Philips Research (see Figure 22). Animated monologues of the iCat were presented to 17 users (10 men, 7 women; 23 – 58 years old, average age 34) in four conditions (2 personalities x 2 TTS-systems, within subjects). Most participants were employees at the High Tech Campus Eindhoven, but none of them was involved in robotics research or in research related to spoken dialogue systems. All of them had good understanding of the Dutch and English language and no hearing problems. Half of the subjects had seen iCat before.

For each condition, the name of the character was given and three utterances were presented through the animated iCat without interaction by the user (Table 19).

Participants assessed the personality of the robot through a questionnaire based on (Boeree, 2004) that measures personality along the big-five dimensions. Twenty of the original fourty items were selected and translated into Dutch – resulting in four items per dimension. Participants scored each of the twenty statements regarding the personality of the robot (e.g. “I find Catherine *shy*”) on a seven-point scale (totally disagree – totally agree). Additionally, they compared the two voices of Catherine (PTTS neutral and Scansoft ‘Emily’) and the two voices of Lizzy (PTTS friendly and Scansoft ‘Karen’) on acceptability, intelligibility, consistency (with other social cues), expertise, trustworthiness, and believability. The stimuli were presented in a balanced order. At the end of the study, participants were interviewed on more general topics, including the good and bad points of the iCat, their TV watching behaviour, and potential applications for iCat.

Figure 22 Setting of first study

Table 19 Sentences used in study 1

Catherine	**Lizzy**
1. There is a movie on channel four that you might like to see. Do you want to hear the description?	1. I found a great movie that is about to start on channel four. I think you’ll like it. Let me tell you more about it. Okay?
2. The title is “Seduced and betrayed”. This is the description: A beautiful and dangerous widow destroys the life of a faithful family man by drawing him in a world of passion and betrayal.	2. The title of this classic is “Seduced and betrayed”. Let’s see what the programme guide says. Okay. A beautiful and dangerous widow destroys the life of a faithful family man by drawing him in a world of passion and betrayal. Sounds cool! What do you think?
3. It is not possible to recommend a programme that matches your preferences. My apologies.	3. Sorry, my friend. I think there’s nothing that you will like. Maybe next time.

4.2.4 Results

The personality questionnaire was analysed to test the reliability of the scales and to test whether significant differences in personalities were perceived. The Cronbach's alphas for the scales were: extraversion 0.71, agreeableness 0.64, conscientiousness 0.76, neuroticism 0.82, and openness to experiences 0.67. These values indicate moderate to high internal consistency. To see whether the differences in the perceived personalities were significant, a Wilcoxon signed ranks test was conducted. The results showed that the personalities were essentially recognized as intended for the three manipulated dimensions extraversion, agreeableness, and conscientiousness (Table 20). No significant difference was found for neuroticism, as intended. However, a significant difference was found between Lizzy and Catherine on the openness dimension, which was unexpected. An explanation for this difference could be that people associate being extravert and talkative with being more open and intelligent, which might have resulted in a higher score on the openness dimension for Lizzy.

During a post-task interview participants were asked to state which of the four combinations was considered the best and which was considered the worst. Most participants found it difficult to answer this question. They had no clear preference and could not give a clear motivation for their choice, but rather based their choice on "just a feeling". Nevertheless, the results clearly show a difference in preference. Lizzy with the Scansoft voice was most often mentioned as the best combination (11/17 participants), while Catherine with the PTTS voice was mentioned most often as the worst combination (9/17 participants) (Table 21).

Table 20 Perceived personality differences

Personality	Catherine		Lizzy		Direction	Significance
Dimension	Mean	SD	Mean	SD		p-value
Extraversion	2.38	1.18	4.93	1.40	Lizzy > Catherine	0.000*
Agreeableness	4.62	1.82	5.34	1.33	Lizzy > Catherine	0.003*
Conscientiousness	5.37	1.01	4.32	1.32	Catherine > Lizzy	0.003*
Neuroticism	3.46	1.71	3.00	1.45	Catherine > Lizzy	0.071
Openness	3.26	1.20	4.29	1.28	Lizzy > Catherine	0.001*

* Statistically significant at $\alpha < 0.05$

Table 21 Best and worst combinations of personality and voice

	Lizzy - Scansoft	Lizzy - PTTS	Catherine - Scansoft	Catherine - PTTS
Best	11	5	1	0
Worst	0	0	8	9

4.2.5 Conclusion and discussion

Lizzy was perceived as more extraverted, more agreeable, less conscientious, and more open to new experiences than Catherine. This matched to a large extent the intentions of the researchers (Table 16). Furthermore, Catherine and Lizzy did not significantly differ on neuroticism. It was quite surprising to see how well participants assessed the personality of the TV-assistant – even after a relatively short meeting of only a few minutes - based on first impression. From these findings it is concluded that it is possible to create recognizable synthetic personalities for the iCat by applying social cues in head and neck motion, facial expressions, speech, and linguistic style. Although previous research on the expression of personality, which we refer to in section 4.2, showed that each of these cues has an effect on personality perception, it was not the purpose of this study to investigate to what extent each of the modalities contributed to personality perception of a robotic character. This is an interesting question that needs further investigation, but is outside the scope of this study. Although participants were not asked directly about their preference for personality, one might be tempted to conclude from the data in Table 21 that Lizzy was more preferred than Catherine. However, strictly speaking such a conclusion is not warranted because the questions focussed on which combination of personality and TTS they found best or worst. It could well be that both selected voices matched better with Lizzy's personality than with Catherine's personality. Based on the remarks about the personalities from participants during the interview, we made a few minor modifications in the personality design. Some participants perceived Catherine as shy or depressive. Therefore, the Catherine agent was made a little bit less introvert by raising its head and establishing somewhat more eye contact with the user. There was no clear preference for a TTS-system. Both systems were acceptable, intelligible, and able to support the other social cues (facial expression, head and neck motion, and linguistic style) in conveying a personality. We decided to use the PTTS system for the second study, since it offered most flexibility to support different personalities.

4.3 TV-assistant design

The goal of the TV-assistant is to help users find an interesting TV-programme. It informs users about programme details (title, description and genre), recommends programmes based on their profiles or a genre that they specify and reminds them about their favourite programmes. Four TV-assistant prototypes were built for the study, one for each combination of the two personalities and the two levels of control. The guidelines described in Table 17 and Table 18 were used for designing the TV-assistant personalities. The dialogue style was adjusted to the two levels of objective control. This meant that the TV-assistant application with low user control could not be operated with user-initiated commands. The robot took the initiative to start a conversation based on predefined rules (time, watching behaviour, etc.). The user could interact by answering the questions of the TV-assistant. For the high user control application, the user could initiate a conversation by giving a command. The TV-assistant responded by performing an action or asking a question. Table 22 shows example dialogues to illustrate the difference between the low control and the high control interaction style.

Figure 23 gives a hierarchical overview of the TV-assistant dialogues. The big round circles are dialogue states. Dialogue 0 represents the idle state, in which the TV-assistant looks towards the television. The other three dialogue states correspond with the three main functions. The text near the arrows explains when the transitions between the states are made. In the high user control condition, this is mostly done by a user command (U) (except for the reminder, since this action is always triggered by the system). For example, if the TV-assistant is in the idle state and the user gives the command to get programme information, the inform dialogue is started. In the low user control condition, the transitions are made once a condition (C) is satisfied, after which the system calls the function. For example, if the user is zapping for more than a number of seconds (N), the TV-assistant starts the recommend dialogue. The smaller circles indicate sub dialogues. In the low control condition, the system guides the user through these sub dialogues (from left to right). In the high control condition, the user starts a sub dialogue by giving a command.

Table 22 Example dialogues to illustrate difference between low control and high control

Low user control (Lizzy)	**High user control (Lizzy)**
Lizzy: “This is a wonderful moment to give you a recommendation. Do you want to help me by specifying the genre?” User: “Yes please.” L: “So, what is the genre that I have to find?” U: “Movies.” L: “Now, let's see if I can find movies. I’ll check the guide for cool programmes.” L: “I would like to recommend you Coming to America. It starts in five minutes on channel two.” L: “Here follows the description: Eddy Murphy is an African prince, who goes to America to find the perfect bride.” L: “Do you want so see it live or should I record it?” U: “Record it.” L: “No problem. You can leave the recording up to me.”	User: “Specify genre.” Lizzy: “So, what is the genre that I have to find?” U: “Movies.” L: “No problem. I set the genre to movies.” U: “Give recommendation.” L: “I would like to recommend you Coming to America. It starts in five minutes on channel two.” U: “Give description.” L: “Eddy Murphy is an African prince, who goes to America to find the perfect bride.” U: “Record programme.” L: “Of course. I’m glad I can record the programme for you. ”

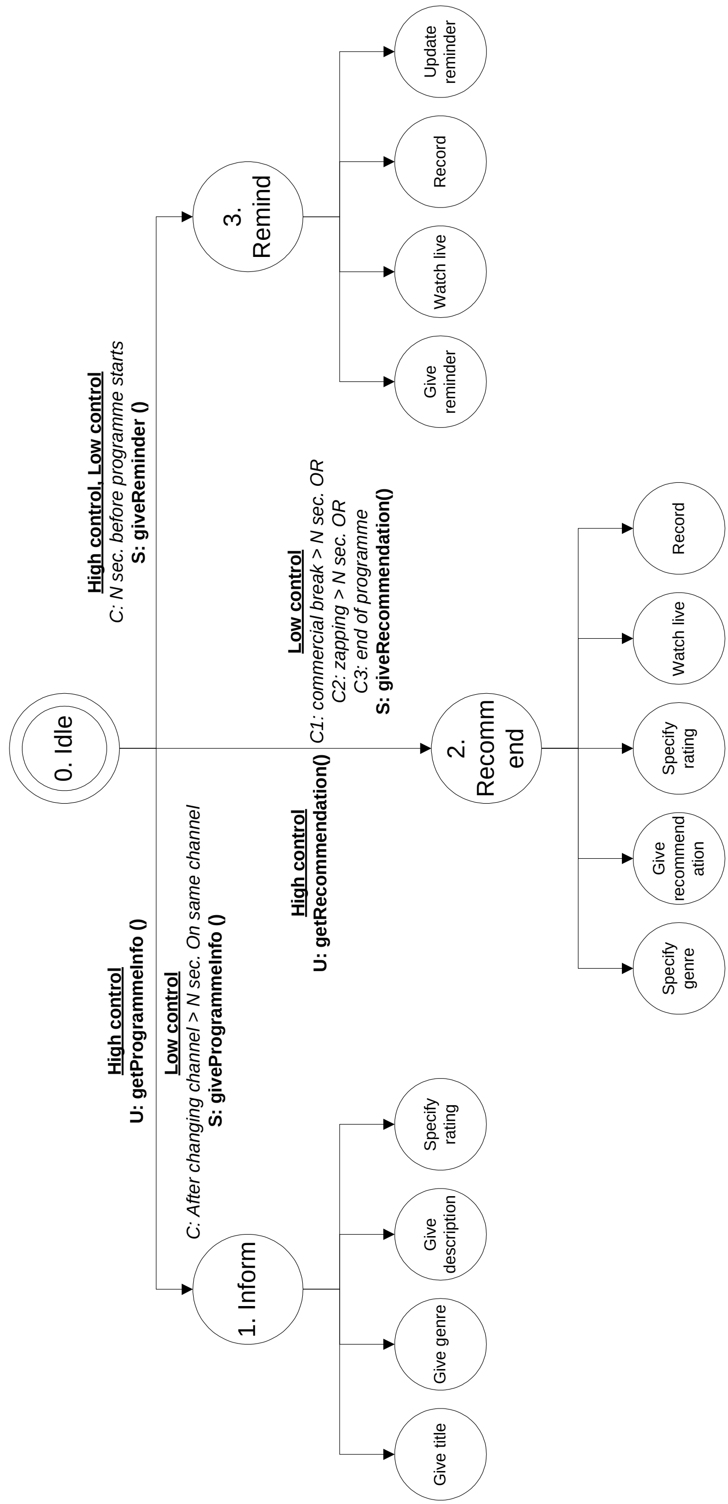


Figure 23 Hierarchical overview of the dialogue system

4.4 Study 2: Preferences for personality and control

4.4.1 Research questions

The research questions for study 2 were the following:

1. What type of personality do users prefer in interactions with the iCat as a TV-assistant?
2. What level of objective control do users prefer in interactions with the iCat as a TV-assistant?
3. Is there an interaction effect between preferences for personality and for the level of objective control in interactions with the iCat as a TV-assistant?

4.4.2 Method

To determine the preference of users we measured the appreciation of the different versions of the robotic TV-assistant. Appreciation was measured in terms of "willingness-to-use" and "recommendation appreciation". "Willingness-to-use" refers to the behavioural intention of a person to use the system in the future. Based on the Technology Acceptance Model (TAM) (Venkatesh & Davis, 2000), the Theory of Planned Behaviour (Ajzen, 1991), and the extended TAM-model for systems with a hedonic nature (Heijden, 2004), four measures were selected for willingness-to-use:

1. *Perceived usefulness*, defined as the degree to which a person believes that using a particular system would enhance his/her task performance.
2. *Perceived ease-of-use*, defined as the degree to which a person believes that using a particular system would be free of effort.
3. *Perceived enjoyment*, defined as the extent to which the activity of using the system is perceived to be enjoyable in its own right, apart from any performance consequences that may be anticipated.
4. *Perceived control*, defined as a person's (subjective) belief about how much control is available (which is a different measure than the objective level of control).

"Recommendation appreciation" refers to one's subjective judgement of the output generated by the TV-assistant. A measure for recommendation appreciation was derived from objective performance measures for recommendation systems: accuracy and coverage. The statements were:

1. "I appreciate the recommendations of Catherine/Lizzy" (direct)
2. "I would like to watch the programmes that Catherine/Lizzy recommends" (accuracy)

3. “I think Catherine/Lizzy recommends all programmes that could be of interest to me” (coverage).

Based on findings of Nass and Lee (Nass & Lee, 2000), the personality of the user was expected to influence the user preference for robot personality. Therefore, the personality of the participants was assessed before the actual study started. It was expected that extravert users would generally be more eager to interact with extravert robots, and introvert users more often with introvert robots. Since the participants' personalities did not vary substantially and were neither strongly extravert nor strongly introvert, this variable will not be discussed in the remainder of this paper.

4.4.3 Procedure and measurements

Thirty-three participants interacted with the robotic TV-assistant individually in a session of about two hours. Two levels of objective control were designed: one with relatively high control for the user and one with relatively low control for the user (and relatively high control for the robot). Orthogonal combination of robot personality (Lizzy vs. Catherine) and user control produced four conditions (2x2-design). Only three conditions were presented per participant, since presenting all four conditions would result in a session with a duration that was deemed unacceptable. The level of control was switched only once per subject and there was a break between the different levels of control, to avoid confusion caused by repeated switching between different interaction styles (or dialogue strategies). The conditions were presented in a balanced order over all participants. Due to time constraints, two participants were only able to complete two of the four conditions. This resulted in 23-25 measurements for each condition (Table 23). One participant was not able to participate in the interview because of time reasons.

In each condition, participants performed three tasks. The goal of the first task was to get information about TV-programmes (title, genre, description) that would facilitate the choice of what to watch. In the second task, participants had to obtain at least one recommendation from the TV-assistant and let her record it. In the third task, participants received a reminder about their favourite programme - which they had indicated at the beginning of the test session - and had to record it. The first two tasks took about five minutes each; the third task was a bit shorter. The prototypes were implemented to work without intervention of the experimenter, using Lernout & Hauspie ASR1600 for automatic speech recognition. However, for some users speech recognition did not work satisfactorily. In those cases, the experimenter simulated the recognition in a “Wizard-of-Oz”-style. Participants were unaware of the simulation. The experimental setting is depicted in Figure 24. After each round, participants were asked to fill out the following questionnaires:

- Personality assessment TV-assistant (adapted from (Boeree, 2004))
- Perceived control (adapted from (Hinds, 1998));
- Perceived ease of use (adapted from (Venkatesh & Davis, 2000));
- Perceived usefulness (adapted from (Heijden, 2004));
- Perceived enjoyment (adapted from (Huang, Lee, & Nass, 2001));
- Recommendation appreciation

The original questionnaires were translated from English to Dutch. For the perceived enjoyment questionnaire both the original English items and their Dutch translations were presented to the participants, since some items were difficult to translate accurately. All questionnaires consisted of statements that participants had to score on a 7-point scale (totally disagree – totally agree). Some questionnaires had to be adapted to the context of the study. All adapted questionnaires can be found in (Meerbeek, 2005). Furthermore, participants were asked to write down any comments and remarks they might have. The session ended with an interview consisting of eleven open questions. The main topics were people's general impression of the TV-assistant, their preferred combination of personality and control, the appearance and voice of iCat, and other possible applications for iCat. The interview took approximately fifteen minutes per participant.

Table 23 Orthogonal combination of personality and user control (2 x 2 design)

	Catherine	**Lizzy**
Low user control	23 measurements	25 measurements
High user control	25 measurements	24 measurements

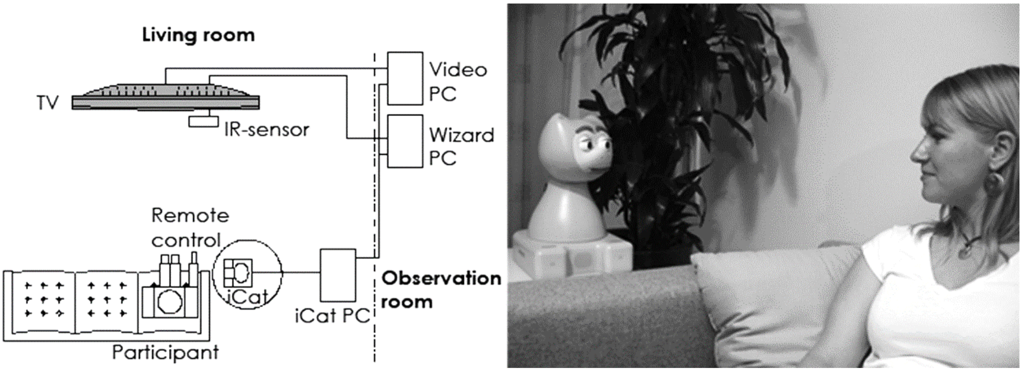


Figure 24 Setting of second study

4.4.4 Results

The Cronbach's alphas were calculated to test the reliability of the scales that were used. Most scales showed a moderate to good internal consistency (Table 24). A univariate analysis of variances (ANOVA) was performed to determine whether there were significant effects. For most measures, observed differences between conditions were found to be insignificant or rather small. In particular, the manipulation of personality did not largely affect the perceived personality. However, the results indicate that Lizzy was perceived as more extravert and more open to new experiences than Catherine (Table 26). The manipulation of level of control did not significantly affect the perceived level of control or one of the other user preference measures. However, the analysis did show significant effects of personality on perceived control, recommendation appreciation, and willingness to use (Table 27). People perceived more user control with the more extravert and agreeable Lizzy than with the more introvert and distant Catherine. Furthermore, people appreciated the recommendation of Lizzy more than the recommendation of Catherine. Additionally, on perceived ease of use and perceived enjoyment Lizzy seemed to have on average more positive scores than Catherine. Overall, participants are more willing to use Lizzy than Catherine. Table 25 shows the means and standard deviations for the user preference measures.

As mentioned earlier, it was decided to present only three of the four conditions to a participant, since presenting all four conditions would result in a session with a duration that was deemed unacceptable. Because of this incomplete block design, the interaction effects could not be computed using the questionnaire results. However, the qualitative results that will be discussed subsequently provide some indications on the interaction between personality and level of user control.

Participants were asked to indicate which of the three conditions (combinations of personality and level of user control) they experienced as the best and the worst. Some of the participants did not have a clear preference and could not point out the best and the worst combination. For the others, the following pattern emerged (Table 28). First, Lizzy was ranked higher (rank 1 and 2) than Catherine (rank 3 and 4), indicating a preference for the more extravert personality. Second, Catherine with high user control (rank 3) was preferred to Catherine with low control (rank 4), whereas Lizzy with low control (rank 1) was preferred to Lizzy with high control (rank 2). This could indicate a preference for a match between personality and the level of user control.

Table 24 Scale reliability study 2 (Cronbach's alpha)

Personality	α	User preference	α
Extraversion	0.71	Perceived control	0.78
Agreeableness	0.62	Perceived ease-of-use	0.85
Conscientiousness	0.54	Perceived usefulness	0.86
Neuroticism	0.35[1]	Perceived enjoyment	0.88
Openness	0.84	Recommendation appreciation	0.80

[1] Removing one item ("relaxed") increases alpha to 0.78.

Table 25 Personality and User Preference for the four conditions - Mean (standard deviation)

	Catherine – Low control	Catherine – High control	Lizzy – Low control	Lizzy – High control
Extraversion	3.50 (0.59)	3.20 (0.50)	3.50 (0.57)	3.48 (0.43)
Agreeableness	4.23 (0.49)	4.40 (0.42)	4.38 (0.61)	4.25 (0.38)
Conscientiousness	4.04 (0.53)	4.00 (0.65)	4.31 (0.68)	4.04 (0.53)
Neuroticism	2.90 (0.69)	2.70 (0.59)	2.87 (0.50)	2.84 (0.60)
Openness	3.86 (0.83)	3.40 (0.64)	3.69 (0.65)	3.84 (0.51)
Perceived control	3.67 (0.55)	3.81 (0.66)	4.04 (0.46)	4.03 (0.49)
Perceived ease-of-use	4.37 (0.89)	4.30 (1.06)	4.53 (1.09)	4.52 (0.98)
Perceived usefulness	4.55 (1.20)	4.46 (1.16)	4.36 (1.06)	4.42 (0.98)
Perceived enjoyment	3.98 (0.56)	4.09 (0.42)	4.27 (0.60)	4.12 (0.49)
Willingness to use	4.14 (0.56)	4.17 (0.64)	4.30 (0.55)	4.27 (0.58)
Recommendation appreciation	4.99 (1.33)	5.01 (1.10)	5.09 (1.16)	5.21 (0.85)

During the interview, participants were also asked about their first impression of the TV-assistant. The numbers between the parentheses indicate the number of participants who made this remark. The most heard positive comments were that the TV-assistant was nice and funny (11), useful (4), and a cosy companion (3). On the other hand, people mentioned that they had to get used to it (5) and that it was still far from a real product (3). Furthermore, the participants were asked to describe the strong and the weak points of the TV-assistant. The most frequently mentioned strong points were the reminder functionality (10), the provision of information about the programme that would follow a commercial break (5), the assistance of the TV-assistant in selecting a programme (5), the easy recording function (5), and the possibility to update the user's profile (4). People appreciated the eye contact (4) and the facial expressions (4). Some weak points that people mentioned were that the TV-assistant was too slow (13), sometimes hard to understand (12), and too noisy – referring to the sound produced by the mechanical parts of the iCat platform (8). Furthermore, they found the set of commands too limited (8) and the speech recognition not satisfactory (7).

Nineteen participants expected their preference to change when using the TV-assistant for a longer period of time. Most of them expected their preference to change from low user control to high user control, since they would learn more about how to use the system. Others expected a change from high user control to low user control, since they assumed that the TV-assistant would learn more about their preferences so it could take the initiative to suggest a programme.

Table 26 Analysis of variance for personality perception

Dependent variable	Independent variable	F	Sig.	Direction
Extraversion	CONTROL	.769	.384	Low control > High control
	PERSONALITY	9.415	.003	Lizzy > Catherine
Agreeableness	CONTROL	1.350	.250	High control > Low control
	PERSONALITY	2.506	.119	Lizzy > Catherine
Conscientiousness	CONTROL	.010	.919	Low control ≈ High control
	PERSONALITY	.312	.579	Lizzy > Catherine
Neuroticism	CONTROL	.708	.403	High control > Low control
	PERSONALITY	.2123	.150	Lizzy ≈ Catherine
Openness	CONTROL	.227	.635	Low control > High control
	PERSONALITY	4.876	.031	Lizzy > Catherine

Table 27 Analysis of variance for user preference measures

Dependent variable	Independent variable	F	Sig.	Direction
Perceived control	CONTROL	.769	.384	High control > Low control
	PERSONALITY	9.415	.003	Lizzy > Catherine
Perceived ease-of-use	CONTROL	1.350	.250	Low control > High control
	PERSONALITY	2.506	.119	Lizzy > Catherine
Perceived usefulness	CONTROL	.010	.919	Low control ≈ High control
	PERSONALITY	.312	.579	Lizzy > Catherine
Perceived enjoyment	CONTROL	.708	.403	Low control > High control
	PERSONALITY	.2123	.150	Lizzy > Catherine
Recommendation appreciation	CONTROL	.227	.635	Low control > High control
	PERSONALITY	4.876	.031	Lizzy > Catherine
Willingness to use	CONTROL	.243	.624	Low control > High control
	PERSONALITY	5.654	.021	Lizzy > Catherine

Table 28 User preference based on interviews

Personality	Low user control	High user control
Catherine	Best: 2 votes	Best: 4 votes
	Worst: 11 votes	Worst: 9 votes
	Overall rank: 4th	Overall rank: 3rd
Lizzy	Best: 6 votes	Best: 4 votes
	Worst: 4 votes	Worst: 4 votes
	Overall rank: 1st	Overall rank: 2nd

Note: 16 of 32 participants could indicate best combination; 28 of 32 the worst combination

4.5 Discussions and conclusions

Considering the results of study 1, we conclude that it is possible to create recognizable synthetic personalities for the iCat by applying social cues in head and neck motion, facial expressions, speech, and linguistic style. However, during study 2, participants could not indicate the personality difference as clearly as in the first study. Why did the personality come across less clearly in study 1?

There are several possible explanations for this. One possible explanation invokes the concept of multitasking. Whereas participants could focus entirely on the iCat during study 1, participants had to perform an additional task during study 2 involving watching television programmes. They had to divide their attention over the television, the task they had to perform, and the TV-assistant. Most participants did not look very often towards the TV-assistant in study 2, so that the variations in facial expression and head and neck motion mostly remained unnoticed. The multitasking nature of the experimental setup may have made participants less sensitive to personality variations than in study 1. Another possibility is that the manipulations of personality were less salient. As may be remembered, it was decided to make some modifications in the personalities as described in section 4.2.5 on the basis of the findings of study 1. Perhaps, these modifications made the differences between the personalities too subtle. Since the questionnaires asked for absolute judgements rather than preferences, it may have been more difficult to find significant differences with the questionnaire than in study 1. On the other hand, many subjects could express a preference when asked to indicate the best and worst combination. Participants also described the two characters in terms that matched the intended personality. During the interview, they spoke about Catherine as being polite, calm, formal, and introvert, whereas Lizzy was labelled as being more expressive, friendlier, and quicker.

The user preference questionnaire results of study 2 showed that participants are more willing to use the extravert and agreeable Lizzy than the more introvert and formal Catherine. They also appreciated the recommendations of Lizzy more than those of Catherine, whereas both used exactly the same recommendation strategy. The results from the interview support the conclusion that the more extravert and agreeable Lizzy was preferred to the more introvert and formal Catherine. These results should be interpreted carefully, however, as half of the subjects had no preference. The questionnaire results demonstrated that there is no (significant) overall preference for low user control or high user control.

Most surprising finding was that people perceived more user control with Lizzy than with Catherine in situations with an equal amount of objective control. This suggests that personality can be used in the interface as a way to influence the level of perceived control. Possibly, the more expressive, informal behaviour of Lizzy is more consistent with a more cooperative relation between user and robot and the more formal behaviour of Catherine induces an impression of high system control. This finding will become even more relevant when personal robots develop into more intelligent and autonomous systems.

There are some limitations to the scope of the two studies. First, the prototypes that were used for the evaluation were somewhat limited in functionality. The programme offering was restricted to thirty programmes and the recommendation algorithm was fairly simple. Therefore, the recommendation did not always match with the preferences of the user. The functionality of the TV-assistant in each task was restricted to the functions that were necessary to complete the task. In addition, the time for each task was limited, which made the interaction during the studies different from how the interaction would be in a real setting. Most participants wanted to complete the tasks within time and did not really watch TV-programmes, as they would do at home. Due to the limited duration of the studies, the results only apply to initial interactions with the TV-assistant and not to the use on a longer term. It would be interesting to investigate the interaction with the robotic TV-assistant in a longitudinal study. Finally, during the studies a single person interacted with the TV-assistant, whereas in a typical household several household members might watch TV together. It should be investigated how a TV-assistant has to deal with these circumstances.

This study concentrated on the expression of personality in the face, in head and neck motion, in speech and in the linguistic style, but it did not focus on an internal representation of personality. Personality is more than these four aspects, as is also described by (Carver & Scheier, 1995). According to their definition, personality is displayed in many ways, such as behaviour, thought and feelings. Future research could investigate the factors that play a role in the expression and the internal representation of a robot personality, and how they affect the personality perception. Another interesting topic for future research is the relation between users' preference for a robot personality and the application context. People might not prefer a personality like Lizzy in an application context that is very different from a TV-assistant. The findings of Chapter 3 indeed confirm this application dependent personality preference, as the preferred personality profile for robotic vacuum cleaners was rather different than the personality profile of Lizzy. Finally, the individual differences in people's preference for a personality need more investigation. Many characteristics of a user might affect his/her preference for a robot personality, such as a user's own personality traits, age, gender, or cultural background.

Part II: Automated Blinds

5 BUILDING AUTOMATION AND PERCEIVED CONTROL

In the second part of this thesis, we shift our focus from automation in the domestic environment to automation in the working environment. As a result of the technological advances and increasing focus on energy efficient buildings, simple forms of building automation including automatic motorized blinds systems found their ways into today's office environments. In a five-month field study, qualitative and quantitative methods were used to investigate how office workers in 40 offices experience and use automatically controlled exterior venetian blinds with options for manual override and switching off the automatic mode. In total, 3433 blinds adjustments (average of 0.86 per office per day) were recorded, of which 73.6% was initiated by the user. Significant correlations between weather parameters and blind adjustments were found, including sunshine duration and user-triggered lowering of blinds ($R = 0.354$), cloud cover and user-triggered lowering of the blinds ($R = -0.281$), and outside temperature and user-triggered raising of blinds ($R = -0.266$). Four blinds usage profiles were identified and the underlying motivations for the different users were described. In the majority of offices, the automatic mode was switched off.

This chapter is based on the following publication:

Meerbeek, B., te Kulve, M., Gritti, T., Aarts, M., van Loenen, E., & Aarts, E. (2014). Building automation and perceived control: A field study on motorized exterior blinds in Dutch offices. *Building and Environment, 79*, 66-77.

5.1 Introduction

5.1.1 Comfort in automated office buildings

The increasing attention for energy efficient buildings combined with technological advances in sensors, processing power, lighting, and networks drive the development of so called 'Smart Buildings'. In line with the Ambient Intelligence vision, it is expected that office buildings will evolve into 'ambient intelligent' office environments (Aarts & Marzano, 2003). Technology will be embedded into the environment, aware of the context, personalized to individuals, and adaptive and anticipatory to their needs. This vision is starting to become a reality in today's office buildings. Simple forms of building intelligence such as occupancy sensing or daylight-based dimming are already common practice. User acceptance of this intelligence is a sine-qua-non for successful adoption of building automation technologies, but at the same time difficult to achieve.

There are clear economical drivers for ambient intelligent office environments. For example, energy and cost savings can be realized by automatically switching off the light when people are not in a room or by dimming the electric light if sufficient daylight is available. Such intelligent behaviour should not only result in energy and cost savings, but also make sure that occupants are satisfied with and feel in control of their working environment. If decisions are based solely on economic criteria such as energy saving, the resulting conditions might not be beneficial for the comfort of occupants. A balance between energy efficiency and occupant comfort needs to be found.

As a large part of the population spends a significant part of the day in an office environment, it is not surprising to see an increasing awareness of user comfort in office buildings. Although comfort is a subjective concept, much research has been done on objective determinants and measures of comfort. Many aspects have been identified that influence the perception of comfort in offices, including environmental aspects (e.g. building characteristics, climate), social aspects (e.g. relationships with colleagues), and personal aspects (e.g. gender, age) (Bluyssen, Aries, & van Dommelen, 2011). It is unclear how all of these different aspects relate to each other and contribute to an overall perception of comfort, but studies have shown the importance of separate environmental aspects such as daylight and electric lighting on the perception of comfort. People who are more satisfied with their lighting rate the space as more attractive, are happier, and are more comfortable and satisfied with their work environment and their work (Boyce, Veitch, Newsham, Myer, & Hunter, 2003). Another important factor that influences an individual's comfort in the work environment is the feeling of control.

5.1.2 Control

As already mentioned in Section 1.1, a sense of control is a robust predictor of physical and mental well-being (Skinner, 1996). Both in the domain of technology acceptance (see section 1.3) and the domain of the built environment, a sense of control is recognized as an important factor influencing comfort and satisfaction. For the purpose of this study, we distinguish between the actual control over the blinds that is available to an individual (i.e. 'automatic mode with manual override' vs. 'manual mode' in which the automatic mode is switched off) and the experienced level of control (i.e. the feeling of being able to adjust the blinds to the desired state).

Veitch describes perception of control as an important psychological process that influences perceived lighting quality and satisfaction with the working environment (Veitch, 2001). In her study, people with dimming control reported higher ratings of lighting quality, environmental satisfaction, self-rated productivity, and even showed more sustained motivation and improved performance on a measure of attention. Similarly, a laboratory study showed that the provision of dimming control for a lighting system resulted in improvements on several factors including mood, satisfaction with the environment, and self-assessed productivity (Newsham, Veitch, Arsenault, & Duval, 2004). Interestingly, providing people with a choice over the lighting –labelled as decisional control (Averill, 1973) - was found to have a negative effect on performance in a creativity task (Veitch & Gifford, 1996b). A questionnaire study on indoor comfort in more than 600 Danish homes revealed that a majority of people prefer manual control of the residential indoor environment (Frontczak, Andersen, & Wargocki, 2012). For electric lighting, 68% of the respondents preferred manual control, only 3% automatic control, and 20% a combination of automatic and manual control (9% did not know). A similar result was found for solar shading with 58% preferring manual control, 8% automatic control, and 12% a combination of the two (22% did not know). Please note that this survey was done in a residential indoor environment and not in a working environment. Lee and Brand have investigated the effect of control over the office workspace on perceptions of the work environment and work outcomes (S. Y. Lee & Brand, 2005). Based on a questionnaire study among more than 200 office workers, they conclude that having personal control over the physical working environment positively influences both job satisfaction and group cohesiveness.

5.1.3 Daylight and blinds

People generally have a clear preference for daylight over electric lighting as a source of illumination (Beute & Kort, 2014; Beute, 2014; Boyce, Hunter, & Howlett, 2003). Studies have shown this preference for daylight also exists in offices for various reasons, including enhanced psychological comfort, increased productivity, a more pleasant office appearance, and assumed health benefits (Heerwagen & Heerwagen, 1986; Veitch & Gifford, 1996a). But there is still only little evidence that daylight indeed enhances work performance, as there are many other factors that potentially influence job satisfaction and performance (Boyce, Hunter, et al., 2003). Also, well-documented scientific evidence for the assumed health benefits of daylight is still only scarcely available (Aries, Aarts, & Hoof, 2015). Nevertheless, Christoffersen and Johnsen found that employees prefer to sit near windows (Christoffersen & Johnsen, 2000). The most positive aspects of a window according to this study in twenty Danish buildings are to have a view out, to be able to check the weather outside, and to have the ability to open the window. Others investigated the impact of illumination, sunlight penetration, and view through a window in an office setting on job satisfaction, general well-being, and intention to quit the job (Leather, Pyrgas, Beale, & Lawrence, 1998). Interestingly, not the level of illumination was important, but rather the size of the sunlight patches in the room and the proportion of natural elements in the available view. The area of sunlight penetration was directly and positively related to job satisfaction and general well-being, and negatively related to intention to quit the job. In sum, windows can provide many benefits to office employees.

However, windows can also be a source of visual and thermal discomfort and therefore they come with various forms of blinds to control the amount of daylight that enters through the window. Glare is known to be a primary factor driving blinds usage (O'Brien, Kapsis, & Athienitis, 2013; Van den Wymelenberg, 2012). Several studies investigated the use of manual blinds and show that people do not regularly change the blinds positions (Escuyer & Fontoynont, 2001; Inoue, Kawase, & Ibamoto, 1988; O'Brien et al., 2013; Rea, 1984). People generally lower the blinds to block direct sunlight, but often forget to retract them. If people retract blinds, they mainly do this to increase daylight entrance, to save energy of electric lighting, or to create a view (Galasiu & Veitch, 2006). Interestingly however, others found that in 88% of the cases when the blinds were lowered automatically, people manually raised them within 15 minutes (Reinhart & Voss, 2003).

Reinhart and Voss investigated the use of an automated blind system with manual override (but no option to switch off the automated behaviour) in six 1-person and four 2-person offices at the south-south-west façade of a building in Germany. The offices did not have active air-conditioning and used daylight dimming to provide a minimum of 400 lx on the work plane. The threshold for lowering or retracting the blinds automatically was set at 28 klx (vertical illuminance measured at the façade). The participants were informed about the fact that their blinds usage was monitored. The study ran from end of March to early December. The authors found that people are more likely to accept automatic retracting than automatic lowering of blinds. Lowering of the blinds was only accepted if incident vertical illuminance on the façade exceeded 50 klx (corresponding to incident solar irradiance of around 450W/m^2) or if direct sunlight above 50W/m^2 hit the work plane. Furthermore, they registered on average 3.6 blind adjustments per office per day, of which 47% was triggered by the system.

Guillemin and Morel developed and evaluated a self-adaptive integrated system for energy and comfort management in buildings, in which the blinds control system was optimized for visual comfort if a user was present and for thermal comfort in absence of a user (Guillemin & Morel, 2001). Although the solution demonstrated its potential for reducing the energy consumption, the questionnaire results showed that users quickly got angry at the automatic system when it did not take into account their wishes.

Other researchers investigated office workers response to an automated interior venetian blind system with a linked electric lighting system (Vine, Lee, Clear, & Dibartolomeo, 1998). In a pilot study, 14 participants experienced three modes of operation of the system during sessions of one hour per mode. The three modes varied in degree of control that was available to the user. In the 'automatic' mode, the system worked fully automatically and was configured to block direct sun at all times throughout the day and adjust electric light and venetian blinds such that the light level at the work plane met the designed level (540-700lx). The slat angle of the venetian blinds could be set horizontal to maximize the outside view, but the blinds could not be retracted. In the 'auto user control' mode, users could indicate their preferences for illuminance levels, delay time for switching off lights, horizontal blinds position, blinds adjustment interval, and magnitude of blinds motion to the automatic system. The third mode was a 'manual' mode in which participants could manually control the blinds and lights as they liked. The general levels of satisfaction and dissatisfaction were similar among the three modes of operation, although there was a tendency that in the manual control mode participants were more satisfied with the lighting conditions than in the auto user control mode. Participants seemed to be least satisfied with the automatic mode. However, the sample size and time frame of the study, as well as the differences found, are too small to make conclusive statements about the effect of control mode on satisfaction with the lighting. The authors recommended a larger scale long-term user study on the acceptance of automated daylight and lighting systems.

Sadeghi and colleagues performed a comparative study on occupant interactions with shading and lighting systems using four different control interfaces, including a fully automatic system, an automatic system with manual overrides via a remote control, manual control via a wall switch, and manual control via a web interface (Sadeghi, Karava, Konstantzos, & Tzempelikos, 2016). The fully automatic system resulted in the lowest scores on comfort. Comfort votes were increased when manual override was possible or when manual control was offered via the web interface or wall switch. The authors further emphasize the importance of accessibility of the controls. Similarly, Bakker and colleagues showed that having the option to overrule the automated façade leads to higher user satisfaction with light levels on the work plane and in the room (Bakker, Oeffelen, Loonen, & Hensen, 2014).

Based on a literature review, Galasiu and Veitch concluded that photocontrolled lighting systems have best acceptance when there is individual override control (Galasiu & Veitch, 2006). Integrated control for both lighting and shading can be acceptable, but have highest acceptance when a degree of manual control is provided. Another literature review on dynamically controlled shading systems confirms the importance of simple manual controls for acceptance of automated shading systems (Konstantoglou & Tsangrassoulis, 2016). Although these cited studies clearly show the importance of personal control for occupants' comfort, several studies highlighted that occupant control of blinds and lighting can significantly increase energy demand in a building (Gunay, O'Brien, Beausoleil-Morrison, & Huchuk, 2014; Haldi & Robinson, 2011). These findings suggest that the optimal solution for balancing energy saving and user comfort would be a system that combines system control and user control. However, the authors stated that few real-life studies on usage and user acceptance of this type of systems exist. Van Den Wymelenberg presented an overview of the existing body of research on how occupants use blinds (Van den Wymelenberg, 2012). In the 50 buildings that have been included in the various field studies, the main factors that affected the level of blind occlusion were orientation, sky condition, season, time of day, view type, and the type of cooling system. Due to the different methods that are being used and the mixed results of the various studies, it is difficult to generalize the findings on blind occlusion. The author stated there is not enough literature on blind use frequency, in particular for motorized and automated blind systems and recommended more large-scale real-life studies.

5.1.4 Problem statement

The related work shows the importance of appropriate daylight control for energy saving and user comfort in the working environment. As a result of the technological advances and increasing focus on energy efficient buildings, automatic daylight management systems are being developed and deployed in buildings. But how do occupants experience and use these automated systems? Most previous studies were conducted in a laboratory study, dealt with manual blind systems, only ran for a very short period, or only included a few offices. Additional research is needed to improve the understanding of how people use and experience automated blind systems. In the field study that is reported in this chapter, it is investigated how office workers in 40 offices experience and use automatically controlled exterior venetian blinds - with manual override and option to switch off the automatic mode - in a real working environment during five months. Such a large scale and long-term evaluation has to our knowledge not been done before. The findings can help to improve future daylight and energy simulations and designs of automated blinds systems.

5.2 Methodology

5.2.1 Research questions

The aim of this research is to acquire a better understanding of current behaviour of office occupants with respect to the control of daylight entrance in office buildings. More specifically, the effect of user-controlled and system-controlled (automatic) changes of exterior venetian blinds on occupants' experience of the blinds system and satisfaction with the indoor climate is investigated. How often are the blinds adjusted by the user and by the system? What are the main reasons for adjusting blinds? What are the effects of time of year and weather conditions on usage of the blinds? What proportion of building occupants enables the automatic mode of the blinds system? What are the effects of the control setting ('automatic mode' versus 'manual mode') on the satisfaction with the indoor climate? To answer these questions, a combination of quantitative and qualitative research methods is used. Based on the results of previous studies on blinds usage, expectations are formulated in Table 29. Please note however that due to many methodological differences between this study and the previous studies it is difficult to compare the results directly.

Table 29 Expectations based on related work

Question	Expectations
How often are the blinds adjusted by the user and by the system?	The results are expected to be in line with the findings of (Reinhart & Voss, 2003)(on average 3.7 blind manipulations per day and office of which 47% adjusted by the system)
What are the main reasons for adjusting blinds?	Visual comfort, thermal comfort, privacy, the quality of the view (Van den Wymelenberg, 2012)
What are the effects of time of year and weather conditions on usage of the blinds?	Relatively more blind changes occur in summer and autumn than in winter (Van den Wymelenberg, 2012) A correlation is expected between sky condition and blind usage. (Van den Wymelenberg, 2012)
What proportion of building occupants enables the automatic mode of the blinds system?	Less than half of the building occupants are expected to have the automatic mode enabled (based on the questionnaire study in a home context by (Frontczak et al., 2012)
What are the effects of the control setting ('automatic' vs. 'manual') on satisfaction with the indoor climate?	People using the manual mode experience being more in control than users of the automatic mode and are - as a result - more satisfied with the indoor climate.

Figure 25 Study setting: south façade of office building (left), 2-person office with indoor roller shades and external blinds (centre), blinds controller in the office (right)

5.2.2 Study design

The field study was conducted in two- and three-person offices located at the south orientated façade of an office building on the High Tech Campus in Eindhoven, the Netherlands (see Figure 25). Most employees in the building can be characterized as knowledge workers of a large multinational company with a high education level. The employees have a variety of cultural backgrounds. The selected offices are located at the 3rd to 7th floor with an unobstructed view on natural scenery including a few buildings in the distance. The façade is equipped with automatic motorized exterior venetian blinds with manual override and option to switch off the automatic mode. These blinds are lowered automatically if the roof-top light sensors detect intensities exceeding a threshold value of 16klx (horizontal) and raised at fixed times (21:00) or with wind speeds exceeding 30 km/h. Furthermore, each room is equipped with three manually and individually operable indoor roller shades in the form of screens, and one controller for the exterior blinds. With this controller, occupants can choose to set the blinds in automatic or manual mode and use up and down keys to manually control the blinds height and slat angle. Each room is equipped with fluorescent lighting that is controlled automatically based on occupant presence (on/off) and daylight linked dimming for the lights near the window. Occupants are not able to manually adjust the electric light. The daylight linked lighting is set up to provide a minimum of 500 lx (horizontal illuminance) on the desk. All the described blinds and lighting systems are unmodified commercially available products that were installed in the building a few years before this study started.

Two main data collection methods were used in the study. First, the exterior blinds usage was quantitatively monitored during 21 working weeks (July – December 2011). Second, qualitative methods were used, including a diary study and semi-structured interviews with a subset of the building occupants, to investigate satisfaction with the indoor climate, blinds usage, and daylight. People were not informed that their blinds usage was being monitored to avoid any deviation from their normal usage. Only the building occupants who took part in the diary study and the semi-structured interviews (25% of the total number of monitored offices) were informed about the monitoring study, however this happened only near the end of the monitoring period. The study procedure was approved by an internal ethical committee.

5.2.3 Monitoring blinds usage

All exterior blind adjustments were monitored in 45 offices during a period of 21 weeks (25th of July 2011 – 16th of December 2011). It would be very time consuming to manually gather and analyse the data. On the other hand, it would be very costly to install sensors or make adaptations to the existing blind controls in all these offices for capturing the data. Therefore, a webcam was installed facing the south façade of the building of interest. This camera captured an image of the façade every six minutes during the period of the field study (see Figure 26). Only the images taken on working days (Monday to Friday) between 8:00 and 18:00 hours were selected for further processing. For privacy reasons, a low resolution camera was used such that participants could not be identified on the images. A computer vision algorithm was developed to automatically process the images and classify the blinds position for a particular office at a particular time. Figure 27 shows a schematic representation of the blinds position classification. It should be noted that the angle of the blind slats could not be monitored due to the limited resolution of the camera, so only the height of the blinds was determined (blind position). First, the image of the façade was cropped and a raster structure was created to divide the images in cells, such that each cell contained one office. In order to train the system to automatically classify the blinds position, a manual classification was done for a random set of images. Based on the training set, the software could automatically classify all remaining images with an accuracy of over 90%. The usage of the manually operable interior shades was not included in the analysis, as it was technically too complex to automatically derive the manual shades positions from the low resolution images. Moreover, our main interest is in experience and use of the automated exterior blind system.

In addition to the blind status, the following parameters have been collected during the test period from a nearby weather station of the KNMI (Royal Dutch Meteorological Institute): outside temperature (° Celsius); relative sunshine duration (hourly-average in tenth of an hour); global radiation (Joule/cm^2); cloud cover (in oktas, with higher numbers indicating more cloudy conditions); and outside relative humidity (percentage).

Figure 26 Example of original image as captured by the webcam every 6 minutes

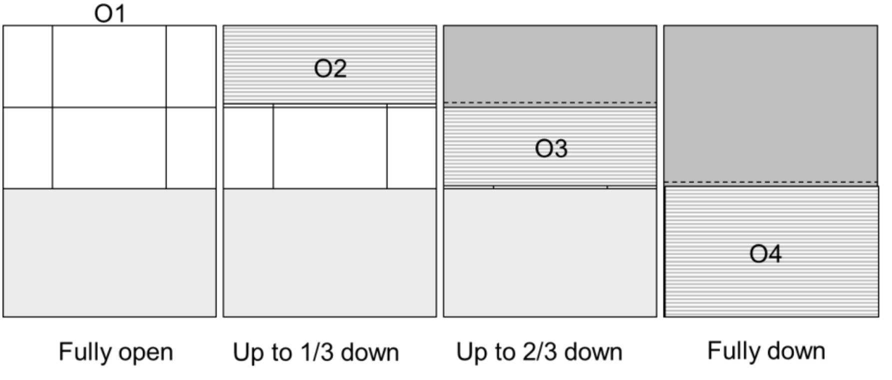


Figure 27 Blinds position classification (from left to right): O1 – fully up; O2 – between fully up and one-third down; O3 – between one-third and two-third down; O4 – between two-third and fully down.

5.2.4 Qualitative measures

Qualitative data were gathered via a diary study and semi-structured interviews with building occupants on satisfaction with the indoor climate and the blinds usage. For this part of the study, two groups of blinds users were selected: nine occupants who used the automatic mode (in five offices) and eight occupants who did not use the automatic mode (in five offices). All offices were occupied by two or three persons. These groups were formed based on their current setting of the 'automatic mode'-switch as shown in Figure 25 on the right. Occupants were asked to maintain their setting of the 'automatic-mode' switch (either 'automatic' or 'manual') for the duration of the diary study.

The 17 occupants in the 10 selected offices were asked to complete a diary during 10 working days, from the 23rd of November till the 6th of December 2011. The diary started with an introduction and explanation of the study, followed by a questionnaire about general personal information, including age, gender, visual aids, number of people in the office, number of days working in the office, and number of hours working per day. Each participant was also asked to make a drawing of the room layout and indicate their own position to support interpretation of the results by the researchers. Each day, the participants judged the indoor climate on the following aspects: daylight, electric light, temperature, air quality, and room acoustics (see Table 31). Furthermore, they listed all their adjustments of the exterior blinds as well as the manually operable roller shades, including the reasons for making the adjustments (Table 30). The participants judged the indoor climate only if they were present that day, so the number of responses differs per day. At the end of the day, they made an overview of their activities in the office on a timeline. After 10 working days, the researchers interviewed the participants about their answers in the diary and asked additional questions on comfort of the working environment and the automated blind system (see Table 32).

Table 30 List of blind adjustments in diary

Topic	Question	Answer option
Blind adjustment	What	Outside blinds / Inside blind left / Inside blind centre / Inside blind right / Switch ("0"-"auto")
	How	Up / Down / Rotate (i.e. changing blind slat angle)/ Switch "0" to "auto" / Switch "auto" to "0"
	Who	Me, while my colleague is / is not in the room Another person
	Why (multiple answers possible)	I perceive too much light on my screen/desk I perceive not enough light to perform my tasks I perceive glare I perceive a too high / too low temperature I want to create a view outside Other: …
	Acceptance (only if adjustment by other)	I agree with the adjustment I do not agree with the adjustment I do not care about the adjustment
Activity before adjustment	What	Reading / Writing / Meeting / Other: …
	Where	Computer / At my desk / Not in my office / Other: …
	Who	Individual / Duo / Team (>2) / Other: …
Activity after adjustment	Activity change	Yes/No
	What	Reading / Writing / Meeting /Other: …
	Where	Computer / At my desk / Not in my office /Other: …
	Who	Individual / Duo /Team (>2) /Other: …

Table 31 Daily questions in the diary

Question	Answer options
1a) How do you judge the daylight in your office today?	Comfortable, Somewhat comfortable, neutral, somewhat uncomfortable, uncomfortable
1b) If it is not comfortable, it is because …	It is too bright, It is too dark, It is changing too much during the day, [other]
2a) Did you experience glare today that was caused by daylight?	Yes / No
2b) If yes, it was…	Intolerable, Disturbing, Noticeable, Barely perceptible
3a) How do you judge the artificial light in your office today?	Comfortable, Somewhat comfortable, neutral, somewhat uncomfortable, uncomfortable
3b) If it is not comfortable, it is because …	It is too bright, It is too dark, It is changing too much during the day, [other]
4a) Did you experience glare today that was caused by artificial light?	Yes/No
4b) If yes, it was …	Intolerable, Disturbing, Noticeable, Barely perceptible
5a) How do you judge the room temperature in your office today?	Comfortable, Somewhat comfortable, neutral, somewhat uncomfortable, uncomfortable
5b) If it is not comfortable, it is because	It is too cold, It is too warm, It is changing too much during the day, [other]
6a) How do you judge the room acoustics in your office today?	Comfortable, Somewhat comfortable, neutral, somewhat uncomfortable, uncomfortable
6b) If it is not comfortable, it is because …	It is too noisy, It is too quiet, It changes too much during the day, [other]
7a) How do you judge the air quality in your office today?	Comfortable, Somewhat comfortable, neutral, somewhat uncomfortable, uncomfortable
7b) If it is not comfortable, it is because …	It is too dry, It is too muggy (humid), [other]
8) How do you score the overall indoor climate today?	Rating between 0-10 with 10 being the most comfortable
9) What are things worth mentioning regarding the indoor climate (e.g. remarkable or extreme situations)	Open question. Answer in following categories: daylight, artificial light, room temperature, room acoustics, air quality, other
10) Are there any other possible things that influenced your comfort level (e.g. being ill)	Open question.

Figure 28 Example images as collected during the trial period with all exterior blinds open (left) and some exterior blinds closed after an automatic trigger (right)

Table 32 Questions semi-structured interview

Question	Typical follow-up questions
How did you experience the indoor climate and the blind system?	Most important things someone noticed during the study. Things people want to mention.
Was your usage of the blind system the past 10 days representative for your normal working day?	If not, how did the study influence how you use the blinds? Did you use it more or less often? How down/up, use the switch?
To what extent do you feel in control of the blind system / indoor environment	Is that enough, or do you prefer to have more control? In which respect do you prefer more control?
Could you describe how you think the blinds system functions?	Automatic: when does it close / open? Manual: do you completely control the blinds?
What are the main reasons for adjusting the blinds?	How does energy usage influence your blinds usage? Do you think of energy saving; for example when you open the blinds to reduce artificial light?
How do you experience the use of the blinds in cooperation with your colleague?	Do you agree with each other's adjustments? Do you feel limited in using blinds because of your colleague(s)?
Do you feel you were limited in answering the questions in the questionnaire?	
Are there other things you want to mention?	

5.3 Results

5.3.1 Quantitative results

The study was conducted in Eindhoven, The Netherlands (51.4344° N, 5.4842° E) from July to December in a temperate maritime climate. On working days (Monday – Friday) between 8:00 and 18:00, hourly averages were registered for the following parameters: outside temperature, relative sunshine, global radiation, cloud cover, and outside relative humidity. Table 33 presents the average values for each week of the study. The results indicate that various sky and weather conditions occurred during the trial period. For example, the average week temperatures ranged from 5.9-22.0° Celsius and the global radiation varied between 21-163 J/cm^2.

Next to the five weather parameters, the blinds adjustment data were collected between week 29 and week 50 in 2011 (see Figure 28). Due to a temporary power cut of the monitoring system, the data of week 40 have been excluded from the analysis. Data of 100 working days remain for the analysis. For five offices incorrect or incomplete blinds usage data were captured, and these offices were excluded from the dataset. As a result, the data of 40 offices were included in the dataset. In total, 10.000 images (20 weeks x 5 work days x 10 hours x 10 images per hour) of the exterior blinds status were analysed per office, resulting in a dataset of 400.000 images in total.

Table 33 Week averages for five weather parameters

Week	Temp (^{0}C)	Rel. sunshine	Global radiation (J/cm^2)	Cloud cover (okta)	Relative humidity (%)
29	17.7	1.4	111	7.6	71.5
30	18.4	2.2	117	6.8	77.5
31	22.0	5.0	159	4.7	68.3
32	18.6	3.5	140	6.4	68.6
33	20.1	5.6	163	4.9	66.5
34	21.0	3.0	101	6.3	79.0
35	17.6	4.4	124	4.9	69.8
36	16.6	1.8	70	7.2	81.3
37	17.4	4.5	106	5.0	70.5
38	16.6	4.7	106	5.4	72.1
39	21.9	7.9	120	1.4	64.8
40	16.6	3.1	65	6.1	74.3
41	14.4	3.6	62	5.5	76.7
42	9.8	3.8	62	5.3	81.9
43	12.2	5.5	66	3.6	72.6
44	15.3	5.2	59	4.4	75.7
45	9.5	3.2	38	4.9	85.4
46	6.6	5.3	46	2.4	81.0
47	7.1	1.1	21	7.0	95.3
48	8.1	3.9	30	3.7	81.4
49	5.9	2.6	24	5.8	76.5
Average	14.9	3.9	85	5.2	75.7
Min	5.9	1.1	21	1.4	64.8
Max	22.0	7.9	163	7.6	95.3

A list of blinds adjustments was created by comparing the external blinds position (see Figure 27) at time *t* with the blinds position at time *t-1*. Additionally, the type of adjustment was registered: 'system-triggered up' referring to a raise of the blinds initiated by the system, 'system-triggered down' referring to a lowering of the blinds initiated by the system, 'user-triggered up' referring to a raise of the blinds initiated by the user, or 'user-triggered down' referring to a lowering of the blinds initiated by the user. Ideally, one would have direct access to the control data of the automated blind system to determine whether the user or the system triggered the blind adjustment, but that was not available for this study. As an alternative, the type of adjustment was determined through a post-hoc analysis of the list of blinds adjustments. There were nine offices that used the automatic mode throughout the study, but a slightly lower threshold was taken for classifying a blind adjustment as a system-triggered event (six or more simultaneous blind changes) for a few reasons. First, in some of the nine automatic offices the automatic mode might be temporarily switched off. Second, the inaccuracies of the blinds classification algorithm might lead to miss out on a blind manipulation and this should be taken into account. For example, a blind change could be classified with the wrong occlusion level or not be detected at all due to the outside light conditions or light reflections in the camera image. Therefore, if after a summation of blinds changes at time *t*, more than five identical changes were registered, it was assumed that these changes were triggered by the system. The probability that more than five office users initiated identical blinds adjustments within a period of six minutes was deemed negligible. A manual cross-check through visual inspection for a random selection of full-façade images was done. For all inspected images, the type of adjustment could be correctly determined by this simple rule. It should be noted however, that this classification of user- and system-triggered adjustments is an approximation. Roughly 15% of all blind adjustments was in the 'grey zone' of 6-8 simultaneous blind changes.

In total, 3433 exterior blinds adjustments were registered of which 905 were system-triggered adjustments (26.4%) and 2528 user-triggered adjustments (73.6 %), see Table 35. Figure 29 displays the number of registered adjustments per hour. The graph shows that on average most adjustments are done between 8:00 and 9:00. The total number of adjustments gradually declines during the course of the day but slightly increases after 16:00. System-triggered lowering of the blinds occurred most often in the early morning, while user-triggered lowering of the blinds mostly occurred in the late morning. Figure 30 shows the total number of adjustments per week of the trial split per type of adjustment: user-triggered or system-triggered. Overall, there are on average more adjustments in the third trimester of the trial (week 43-49) than in the first two trimesters (week 29-42). With means of 222.4 (SD = 52.6) and 113.6 (SD = 27.4), this difference was statistically significant (p=0.001). The number of system-triggered adjustments was relatively stable throughout the trial period, while the number of user-triggered adjustments varied largely. In particular in the last trimester of the trial the differences between the number of system-triggered and user-triggered adjustments are remarkable. Table 34 shows the correlation coefficients for the five weather parameters and the number of blinds changes per type of adjustment. Strongest correlations were found for 'sunshine duration' and 'user-triggered down' (0.354), 'cloud cover' and 'user-triggered down' (-0.281), and for outside temperature and user-triggered up (-0.266).

Table 34 Correlations between adjustments and weather parameters (per adjustments type).

Type of adjustment	Outside temp.	Sunshine duration	Global radiation	Cloud cover	Relative humidity
System-triggered up	-0.121[b]	0.016	-0.085[b]	0.001	0.108[b]
System-triggered down	-0.068[a]	0.141[b]	0.038	-0.066[a]	0.083[b]
User-triggered up	-0.266[b]	-0.065[a]	-0.185[b]	-0.135[b]	0.074[a]
User-triggered down	-0.167[b]	0.354[b]	0.167[b]	-0.281[b]	-0.016

[a] statistical significance at 0.05; [b] statistical significance at 0.01.

Table 35 Type and number of blind adjustments (sum for all offices during trial)

Type of adjustment	Number of adjustments	% of total
System-triggered up	130	3.8%
System-triggered down	775	22.6%
System-triggered adjustments (sum of up and down)	905	26.4%
User-triggered up	1173	34.2%
User-triggered down	1355	39.5%
User-triggered adjustments (sum of up and down)	2528	73.6%
Total up	1303	38.0%
Total down	2130	62.0%
Total adjustments	3433	100.0%

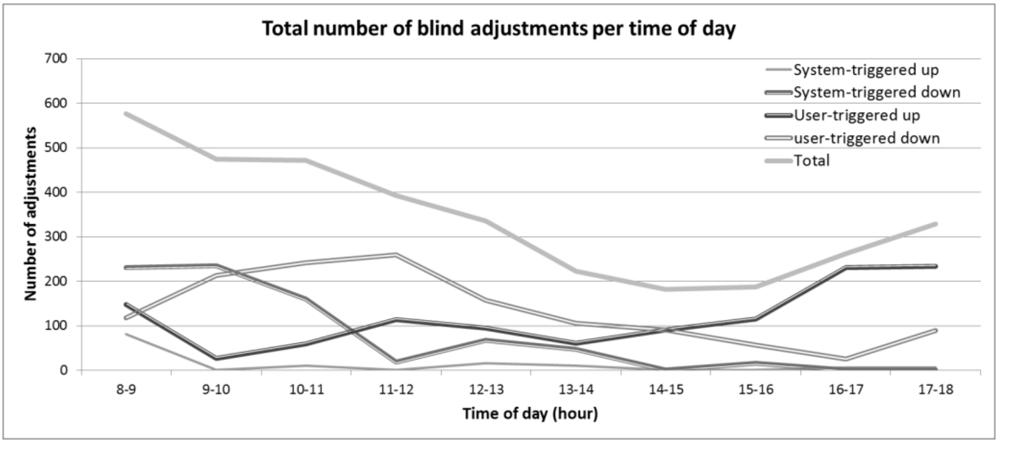


Figure 29 Total number of blind adjustments per time of day

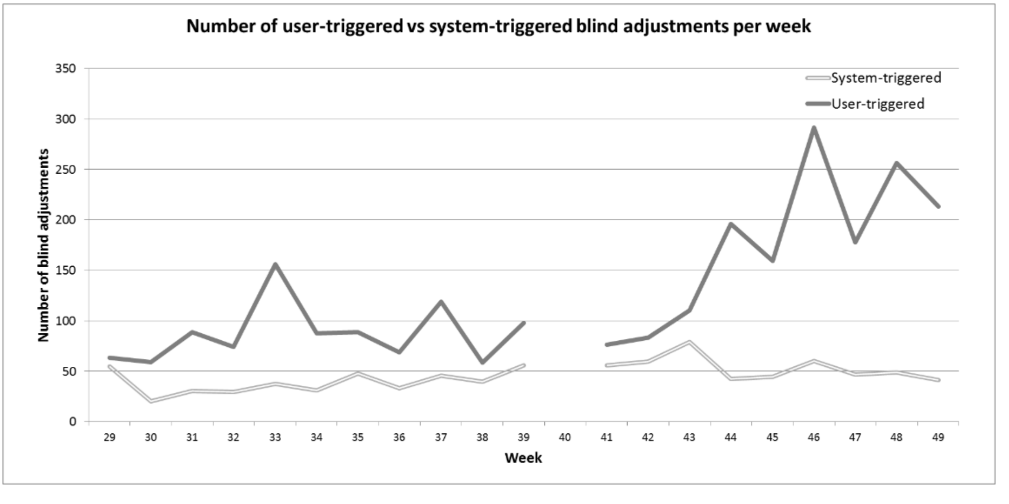


Figure 30 Number of user-triggered and system-triggered blind adjustments per week

The overall average of blinds adjustments per office during the trial period is 85.8, with a minimum of 0, a maximum of 198, and a standard deviation of 54.0. Hence, the average number of adjustments per working day is 0.86, but with a large spread across offices. Nine out of forty offices (22.5%) used the automatic mode of the exterior blinds system throughout the trial period, while a large majority of offices (77.5%) never used the automatic mode or only during a small period of the trial. The first is referred to as the group 'auto mode' and the latter as the group 'manual mode'. The average number of adjustments for manual mode offices is much lower than for auto mode offices (73.6 respectively 127.9). Besides the large variation in the average total number of adjustments, there are also large variations in the type of adjustments (user-triggered versus system-triggered) between auto mode and manual mode offices. In the auto mode group, on average, 39.6% of all adjustments are initiated by the user. In the manual mode group, on average 92.4% of all adjustments in an office are initiated by the user. The remaining 7.6% of adjustments are triggered by the system and can be the result of manual mode users switching to automatic mode during a part of the trial, coincidentally adjusting the blinds at the same time and in an identical way as the automatic system, errors of the classification software, or special circumstances in which automatic adjustments are enforced upon the user (e.g. cleaning windows, high wind speed).

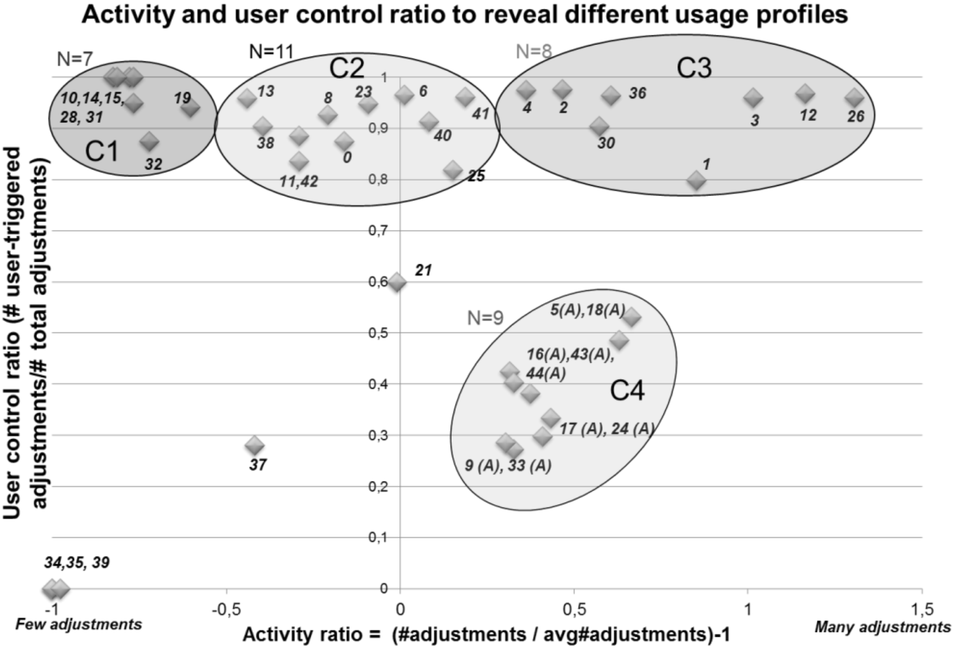


Figure 31 Activity and user control ratio reveal different usage profiles.

Table 36 Daily weather data and overall comfort scores during diary study

Day	Temp (^0C)	Rel. sunshine	Global radiation (J/cm2)	Cloud cover (okta)	Rel. humidity (%)	Overall comfort Auto (average)	Overall comfort Manual (average)
1	9.3	0.0	8.5	8.7	98.8	8.3	8.0
2	8.5	0.4	24.4	7.5	93.0	7.2	8.2
3	7.4	0.0	7.8	7.1	93.2	7.8	7.8
4	6.0	6.6	40.9	0.0	81.6	7.5	7.5
5	8.1	2.5	28.1	6.3	78.5	7.7	7.5
6	8.4	5.9	36.3	0.1	75.1	8.0	7.8
7	11.6	0.0	8.6	8.0	85.9	8.0	7.7
8	6.4	2.7	24.9	3.9	86.0	8.0	8.0
9	4.1	2.2	21.5	5.7	82.8	7.2	7.4
10	4.2	2.0	21.5	4.3	85.0	7.6	7.3
10-day average	7.4	2.2	22.2	5.2	86.0	7.7	7.7

Table 37 Number of blind adjustments during diary study

	Auto	Manual	Sum
System-triggered up	7	-	7
User-triggered up	4	21	25
System-triggered down	33	-	33
User-triggered down	4	29	33
Change slat angle	2	12	14
Total	50	62	112

5.3.2 Qualitative results

The qualitative data were collected on 10 subsequent working days from 23rd of November until 6th of December (excluding the weekend) and included four days without sunshine, four days with 20-30% sunshine duration, and two days with around 60% of sunshine. The weather data of the 10 days of the diary study are presented in Table 36. The last two columns in this table show the average overall indoor comfort scores. There are no significant differences in the comfort ratings between auto mode and manual mode users (both average of 7.7 on a 10-point scale).

In total, 112 blinds adjustments were recorded in the 10 selected offices during the 10 working days of the diary study. Table 37 shows the distribution between auto mode and manual mode offices and the type of blind adjustments. In the auto mode group, 10 user-triggered adjustments were made (4 x up, 4 x down, 2 x changes of slat angle), while in the manual mode group 62 user-triggered adjustment were registered (21 x up, 29 x down, 12 x changes of slat angle). Due to the low number of manual adjustments in the auto mode group and the fact that very similar reasons for adjusting the blinds were provided as in the manual mode group, the results for both auto mode and manual mode groups are combined when analysing the key reasons for adjusting the blinds. The prevention of discomfort glare was the most frequently mentioned reason for lowering (70% of all user-triggered lowering events) or changing the blind slats angle (55% of all blind slat angle changes). Thermal comfort was only mentioned in 5% of the user-triggered lowering events, but it should be noted that the questions were asked during winter time (November – December). For retracting the blinds, the most frequently mentioned reason is to create a view outside (52% of all user-triggered up events). In 35% of the user-triggered up events, a lack of light in the room was mentioned. Some less frequently mentioned reasons for manually retracting the blinds are appreciation of direct sunlight or too strong wind. An interesting additional finding was that in 68% of the user-triggered adjustments, participants were alone in the office, while in 32% of the cases their roommate was present. This could indicate that users are hesitant to manually adjust the blinds if other people are present in the room. However, this cannot be concluded as there are no occupancy data. In case of lower occupancy levels, chances that another person is in the room during a manual adjustment are generally lower. Nevertheless, the sense of ownership of manual controls in a social setting would be an interesting topic to explore further, in particular for shared or open plan offices.

Although both user groups were reasonably satisfied with the overall indoor climate, specific elements of the indoor environment were rated as less comfortable than others. The participants were least satisfied with daylight, followed by the room temperature, electric lighting, air quality, and room acoustics. The most frequently used reasons for rating the daylight condition as uncomfortable were: it being too bright (8 times), too dark (7 times), or too much changing (6 times). Table 38 shows the subjective indoor comfort ratings for daylight and electric light split between automatic mode users and manual mode users. The results of the daylight comfort ratings suggest a higher level of comfort for automatic mode users (Mean=1.93; SD=1.26, N=44) than for manual mode users (Mean=2.42; SD=1.30; N=59), but the difference was not significant ($t=-1.93$, $p=0.057$). Similarly, the results of the electric lighting comfort ratings suggest that auto mode users had higher comfort ratings (Mean=1.53; SD=1.01; N=43) than manual mode users (Mean=1.91; SD=0.95; N=57). However, a t-test indicated that this difference was not significant ($t=-1.90$; $p=0.061$). Please note that the objective control over the electric lighting was exactly the same for these two user groups. A possible explanation for these findings will be presented in the discussion section.

The results from the interview show that, overall, the participants in both auto mode and manual mode offices were reasonably satisfied with the indoor climate. Several occupants of a manual mode office mentioned that they want to maximize the daylight entrance and their access to the outside view, as the following quotes illustrate. The number between the brackets after a quote refers to the participant number. “For me, the most important thing is to get sunlight in the environment. This test made me realize that I want daylight so badly that I take some glare for granted.” (P4). “I close the blinds as little as possible. I like to get light in and look outside.” (P10). In contrast, none of the auto mode users mentioned the importance of daylight entrance when asked about their experience in the working environment. Three of the eight participants in the auto mode mention they never use the blinds. “You can control the blinds yourself, but I never do. If it bothers me, I go and sit somewhere else.”(P1).

Interestingly, most auto mode users that we interviewed mentioned that the automatic mode does not work properly. “The automatic system actually never does what you want. Sometimes the blinds go down if you don’t want them to and at other times they go up when you don’t want them to.”(P1). “The automatic system sometimes reacts, sometimes not or it doesn’t solve the problem.” (P16). “We keep the switch on auto, because we do not have time to adjust it constantly and the blinds will always be down and we will not have daylight. That would be a shame.” (P15).

All the manual mode users experienced to be in control over the blinds system. Likewise, most auto mode users indicated that they have sufficient control with the current solution of automatic control with manual override. They were generally satisfied with the indoor environment and do not see the need for more control. “I have sufficient control, because I can adjust the blinds if I want to.”(P1). Some do mention it can be annoying that the automatic blind system does not work properly, but they still feel in control as they can manually override the system if necessary. One auto mode user mentions she prefers an easier manual control. “I didn’t do many manual adjustments. I tried once, but I didn’t understand the interface.” (P16).

Most of the 17 participants of the diary and interview study expressed that they did not think about the working mechanism behind the automated blinds before they started the diary study. When participants were asked about how the automated blinds system works they provided different answers. “The outside blinds go up and down in a random manner. I’ve seen the switch but I don’t dare to use it. I think it reacts to outside temperature and perhaps to the light intensity.” (P13) Most people indicate they have no clue but believe it reacts to the amount of light or sun radiation which is measured at the outside of the building, for example at the façade or on the roof. One person was not aware of the fact that the automatic control exists, while another participant thought the blinds go down depending on what most manual users do. “The blinds go down depending on what most people do who control it manually. If our neighbours lower the blinds, our blinds will go down as well.” (P6)

Table 38 Indoor comfort ratings for daylight and electric light[a,b]

	Daylight		Electric light	
	Auto (N=44)	Manual (N=59)	Auto (N=43)	Manual (N=57)
Comfortable	56.8%	37.3%	76.7%	45.6%
Somewhat comfortable	15.9%	15.3%	0.0%	21.1%
Neutral	6.8%	16.9%	16.3%	29.8%
Somewhat uncomfortable	18.2%	28.8%	7.0%	3.5%
Uncomfortable	2.3%	1.7%	0.0%	0.0%
Median	Comfortable	Somewhat comfortable	Comfortable	Somewhat comfortable

[a] Ratings of 8 auto mode users and 9 manual mode users measured at the end of each working day (for 10 subsequent working days); [b] Percentages indicate the relative number of responses within a category.

5.4 Discussion and conclusion

In this section the results of the study are summarized and discussed in relation to the main expectations presented in Table 29.

5.4.1 Frequency of blind use

In total, 3433 blinds adjustments (average of 0.86 per office per day) were recorded in a period of twenty weeks from July to December, of which 73.6% was initiated by the user. Only 26.4% of the adjustments were triggered automatically, which is much lower than the 47% found by Reinhart and Voss (Reinhart & Voss, 2003). As explained in section 1.3, there are various methodological differences between our study and the Reinhart and Voss study. The most important factor that can explain the difference in the percentage of automatic adjustments is that the majority of users in our study had switched off the automatic mode and did not use it at all during the trial. In the study of Reinhart and Voss, occupants could not switch off the automatic system but only manually overrule it. A similar explanation holds for the lower average amount of adjustments per office per day in our study compared to the findings of Reinhart and Voss (0.86 versus 3.6). Studies with only manually operated blinds generally show lower blind manipulation rates than found by Reinhart and Voss (Van den Wymelenberg, 2012).

Our findings seem to support the statements in the introduction of this chapter that a high user acceptance of automated systems is not easy to achieve; most occupants switched off the automatic mode. The choice to switch off the automatic mode has consequences on the total energy usage in the building. In summer, additional cooling might be needed due to increased solar heat gain if the blinds are still up. More electrical lighting might be needed when people forget to raise the blinds after a period of glare. Chapter 6 presents a simulation of the energetic impact of switching off the automatic mode. It should be noted that in addition to the automatic motorized exterior blinds, manually operable white translucent roller shades were installed inside the offices. The usage of these indoor shades was not monitored (the computer vision software only classified the outdoor blinds status), but occupants might have used these instead of the exterior blinds. Only during the 10 days of the diary study, the indoor shade adjustments were registered by the participants in 10 offices. From the total of 112 adjustments, 39 adjustments involved a change of the indoor roller shade (35%). Most indoor roller shade adjustments were made by manual mode users (31 out of 39). This could indeed indicate that some occupants use the indoor shading as a substitute for the automatic exterior blinds and might further explain the relatively low rate of exterior blinds change compared to the study by Reinhart and Voss. It should also be noted that the main purpose for the indoor roller shade is glare prevention (visual comfort). The white translucent roller shade is less effective for thermal regulation (prevent heat through direct sunlight) than the grey opaque aluminium exterior blinds. So, although the indoor roller shade adjustments might have an effect on energy use, the switching off the automatic mode of exterior blinds is considered to be a more significant factor for determining the energetic impact of blinds usage.

5.4.2 Reasons for blinds adjustments

Participants lowered the blinds mainly to prevent discomfort glare and raised the blinds to create a view outside or increase daylight entrance. This is partly in line with findings reported in other studies (Galasiu & Veitch, 2006; Van den Wymelenberg, 2012). In contrast with the findings of Van Den Wymelenberg, privacy and thermal comfort were hardly mentioned by the participants in the qualitative study. For privacy, this can be explained by the fact that only offices at the third floor or higher participated and visual privacy was of little concern for the occupants. The reason that thermal comfort was not mentioned was likely caused by the fact that the interviews were taken in late autumn with relatively low outside temperatures.

5.4.3 Effect of time and weather

As expected, the results show many significant correlations between weather parameters and the number and type of blinds adjustments. For example, a positive correlation was found between sunshine duration and user-triggered lowering of the blinds, while cloud cover was negatively correlated to user-triggered lowering of blinds. However, the strongest correlations are around $R = 0.3$ making it hard to accurately predict blind adjustments based on weather data only. One of the reasons might be that people are not always present in their office to react to a certain change of weather condition. Another reason is that, for example, during a longer period of sunshine, the blinds are lowered only once and in all the subsequent hours there is no correlation between the sunshine and a blind lowering. Probably, a higher correlation can be found between the weather parameters and the actual blind position (instead of the adjustment).

Clear interactions are observed between the number of blind adjustments and the time of day, where most of the adjustments take place in the morning. An interesting observation was that manual lowering of the blinds tends to happen later in the morning than system-triggered lowering. This could be explained by the fact that the threshold for automatically lowering the blinds (16klx on the rooftop) is lower than typical user thresholds for lowering the blinds, as also found by Reinhart and Voss. Furthermore, it was observed that on average in November and December many more adjustments were made than in the period from July to October. The lower position of the sun in autumn is a plausible reason for this increase in number of adjustments. This is in line with correlations found in previous studies between solar penetration depth and frequency of blinds usage (Inoue et al., 1988). People are more likely to lower blinds if they experience direct glare from the sun. It is remarkable that the number of user-triggered adjustments in the last trimester of the trial is much higher than the number of system-triggered adjustments. A possible explanation is that the automatic system reacts to a fixed horizontal illuminance level at the roof-top of the building throughout the year and does not take into account solar angle.

5.4.4 Blinds usage profiles

Roughly a quarter of the offices in this study used the automatic mode throughout the trial period. This is in line with the expectations based on previous literature that demonstrated the importance of a sense of control and that people generally have a strong preference for manual control over automatic control of shading devices in residential areas (Frontczak et al., 2012). Also in line with previous studies on blinds usage, the number of adjustments varied largely between offices with averages between 0 and 2.0 adjustments per office per day (Van den Wymelenberg, 2012). Based on activity level and user-control level, four types of usage profiles were distinguished (see Figure 31). Each of these usage profiles and suggestions for the underlying motivations are discussed next, based on the quantitative and qualitative results of this study and the findings reported in related work. Please note that the usage profiles and suggested underlying motivations are based on interpretations of the results and need further validation.

About 20% of the offices showed a usage profile that was labelled as 'minimal user control' (C1). These users performed relatively few adjustments, but if the blinds were adjusted it was mainly triggered by the user. The automatic mode is switched off. This group wants to maximize daylight entrance and has a high desire to experience control over the lighting condition. Therefore, they do not accept the automatic system and regard it as something that is more disturbing and distracting than helpful in creating a comfortable work environment. It also blocks the daylight they like so much and it takes away their view to the outside. They only adjust the blinds if they experience severe discomfort from direct sunlight.

The usage profile 'regular user control' (C2) consisted of about 30% of the offices. Compared to the group C1, these users performed slightly more adjustments. Similar to group C1, about 80-100% of the adjustments was triggered manually and the automatic mode was mainly switched off. This group is aware of the indoor climate and manually adjusts the blinds if they experience discomfort or want to restore the view to the outside. As they have a high desire to experience control, they switched off the automatic mode.

The group of 'active user control' (C3) offices, which constitutes about 20% of the offices, can be considered active or very active users of the blinds compared to the groups C1 and C2. Similar to groups C1 and C2, most of the adjustments are done manually. These users are aware of the importance of good daylight conditions in the work environment. They consciously use the blinds to optimize the daylight conditions and feel competent to manipulate the indoor climate to their needs. They switch off the automatic mode as they are not satisfied with the adjustments that are triggered by the system. They find the indoor lighting conditions important and want to control it themselves.

Finally, the group 'system control with manual override' consists of about 25% of the offices. This group is characterized in that these are the only users that did use the automatic mode of the blind system consistently during the trial period. In addition, these offices used manual adjustments to overrule the automatic system (about 25-55% of the adjustments in this type of office was performed manually). These users do not have a high desire to experience control over the daylight conditions. They find other strategies to cope with discomfort from daylight, for example moving away from the window. They consider adjustments of the blinds a 'high effort - low reward' activity. This is partly related to the fact that their perceived competence to effectuate the desired changes is low, because they do not understand how to use the blinds system or how adjustments impact the physical conditions in the work environment. Additionally, they do not care so much about the indoor daylight conditions so the perceived reward of making adjustments is low.

5.4.5 Satisfaction with the indoor environment

It was expected that users in the manual mode offices were more satisfied with the indoor climate than the auto mode users as they had more control over the blinds. The higher level of actual control was expected to lead to higher levels of experienced control, which - based on related work (S. Y. Lee & Brand, 2005; Norman, 1994; Skinner, 1996; Vine et al., 1998) – would lead to higher levels of satisfaction and translate into more positive judgments of the blind systems and the indoor climate. But contrary to the expectations, the comfort ratings on daylight for the users of the manual mode were not higher than the ratings of auto mode users. The results even suggest lower comfort ratings for manual mode users, although the difference was not significant. One possible explanation could be that even the automatic mode users state that they experience being in control over the blinds, as they can manually override the automatic adjustments. One could argue that the actual level of control did not vary between the two modes. Interestingly, also the comfort ratings of the electric light seemed to be lower for the manual mode users than for the auto mode users (although not significant). However, the actual control over the electric lighting was identical: automatic daylight dimming, no user control. This suggests that there is a difference between the two users groups (auto mode and manual mode) and their general comfort ratings, rather than an effect of the actual blinds control condition on the daylight comfort rating. A self-selection mechanism might have caused more critical occupants to be part of the manual mode group (i.e. the more critical occupants already switched off the automatic mode before the start of the trial). People in the manual mode group seems to find it more important to have a comfortable indoor climate and seems to have a higher desire to actively control this, or are simply more critical and more easily dissatisfied in general than people in the auto mode group. Therefore, the difference in comfort ratings between the two groups should be taken with care and might not be related to actual control condition, but rather with personality traits of the persons within the groups. Further research would be needed to test this.

5.4.6 Recommendations

Besides the limitations that were already mentioned in the previous sections of Chapter 5.4, there are a few more to mention. First, although the study was one of the few large-scale field studies on this topic, it still only investigated one building, at one particular location, during only part of the year. It is recommended to repeat this type of study in different settings. For example, in other climates, in open offices, in other seasons, with different automated blinds systems, with other façade orientations, etcetera. It would be interesting to verify the identified usage profiles in these different settings. A second important aspect that limits the generalizability of the results is the specific shading solution that was used: automated exterior blinds (triggering at 16klx at the rooftop sensor) with opt-out option and manual override were combined with manual interior roller shades. Due to technical and practical feasibility, only the exterior blind usage was monitored. The interior shades might have been an important confounding factor that was not measured throughout the field study. Third, more studies are needed to unravel the complex topic of user control in the interaction with building automation systems. Well-controlled studies are needed to investigate the different aspects of control and their influence on satisfaction with the environment, user comfort, system acceptance, and on other relevant aspects of people's wellbeing in the built environment.

5.4.7 Conclusion

An interesting and striking result of this study is that a large majority of the building occupants switched off the automatic mode of the blinds system permanently. Various reasons for not using the automatic mode have been identified. First, most office workers highly appreciate daylight in their work environment and enjoy having a view to the outside world. Second, they generally want to have a sense of control over their working environment. Therefore, they do not accept that a system automatically decides to adjust the blinds on their behalf. This is particularly true when the adjustment is not in line with their current needs (e.g. lowering the blinds when they want to maximize daylight entrance) or when the reason for the automatic adjustment is not clear to the office worker.

Contrary to the expectations, users of the manual mode were not more satisfied with the indoor climate or the daylight conditions than auto mode users. Both manual mode and auto mode users with manual override experienced to be in control over the blinds. This leads to the conclusion that it is not the actual control mode that influences the comfort of office workers, but rather the experienced level of control (i.e. did they experience the level of control to be sufficient for their needs). The needs for control seem to vary per individual,

The study revealed that office workers have different usage profiles that vary in the number of adjustments that are being made and in the proportion of manual adjustments. The underlying factors that might determine the usage profile of an office worker relate to personal significance and self-efficacy. Office workers who consider daylight entrance and access to a view to be important contributors to their level of comfort in the working environment are more likely to manually adjust the blinds and reject automatic adjustments than those who do not. In addition, office workers who consider themselves capable of adjusting the blinds to achieve the desired effects are also more likely to manually adjust the blinds.

To conclude, the results of this field study contribute to the existing knowledge on how office workers experience and use automatically controlled blinds. The extensive monitoring of blinds adjustments in a real setting without any interventions resulted in many interesting quantifiable observations that can be used in daylight research and energy simulations. In combination with the qualitative findings, the results of this study can be used to improve automated blind systems. One of the most important lessons that can be derived from this study is that there are different types of blinds users with different attitudes and usage patterns. When designing automated blinds systems, one should acknowledge and accommodate for these differences and the four user types that were described in this chapter can provide guidance. Also, when performing energy simulations for newly developed automatic blind algorithms one should be aware of the human factor in the equation. Many people are reluctant to accept automatic blind changes and switch off the automatic behaviour if possible, often with less energy savings than the algorithm could potentially offer. Another important result of this study is the observed blinds usage data that provide a genuine insight into the blinds usage in a real and uncontrolled environment, also in relation to the outside weather. The significant correlations found between weather parameters and type of blind adjustments can help to improve automatic blind algorithms design or simulation. However, one should be aware of the limitations and specifics of this study, hence careful when interpreting, generalizing, and using the results for these purposes. But all in all, this study showed that improvements are necessary to increase acceptance of automated blinds systems and create comfortable and sustainable workplaces in the future where office workers feel in control of their environment and can focus on doing their job. Chapters 7 and 8 of this thesis will focus on these aspects. But first, Chapter 6 reports on the impact of various blinds usage profiles on energy usage.

6 Impact of blinds usage on heating and cooling: auto versus manual control

This chapter reports a study on the impact of different usage patterns of an automated blinds system on heating and cooling loads in a Dutch office building. A dataset on the blinds usage of four types of blind users from a five-month observational field study (Chapter 5) was used to simulate the effect of the blinds usage on heating and cooling loads. The results of the field study show that a majority of the building occupants switched off the automatic mode of the blinds system permanently. The simulation results indicate that this significantly impacts the heating and cooling loads in the building. The average load for heating and cooling per office on a working day was significantly lower for occupants using the automatic mode than for the three groups of manual users (43.0W versus 129.0W; $T=-4.99$, $p=0.000$).

This chapter is based on the following publication:

Meerbeek, B., van Druenen, T., Aarts, M., van Loenen, E., & Aarts, E. (2014). Impact of blinds usage on energy consumption: automatic versus manual control. In *Ambient Intelligence* (pp. 158-173). Springer International Publishing.

6.1 Introduction

As we described in chapter 5, windows not only provide daylight and a view, but can also be a source of visual and thermal discomfort. The solar radiation that enters a building through the window can result in heat gain within the building and impact the energy that is needed to cool the building. Blinds control the amount of daylight that enters through the window and therefore not only impacts the lighting conditions but also the thermal conditions in the environment. A vast amount of studies investigated the impact of various daylight control strategies on energy consumption in a building for electric lighting and heating ventilation air conditioning (HVAC) systems (Konstantoglou & Tsangrassoulis, 2016). Our study investigates the impact of the way building occupants use the automated exterior blinds system on the energy consumption for heating and cooling. More specifically, based on the results of the field study as presented in Chapter 5, the differences in heating and cooling loads for different blinds usage scenarios are investigated. Heating load is the amount of heat energy that would need to be added to a space to maintain the temperature in an acceptable range. Similarly, the cooling load refers to the amount of energy that would be needed to remove heat from a space to maintain the temperature in an acceptable range.

6.2 Methodology

6.2.1 Introduction

A simulation of heating and cooling loads was performed to gain insight in the difference in energy consumption that can be attributed to the ways the exterior venetian blinds are being controlled. The simulations were performed with IES Virtual Environment (IES VE). IES VE is a commercially available building performance analysis tool that is commonly used within the building services industry. The outcomes of the simulations were matched with the dataset resulting from the field study reported in Chapter 5 and were converted to hourly heating and cooling loads for all of the offices. Figure 32 presents a schematic overview of the simulation method. Next, each step is explained in more detail.

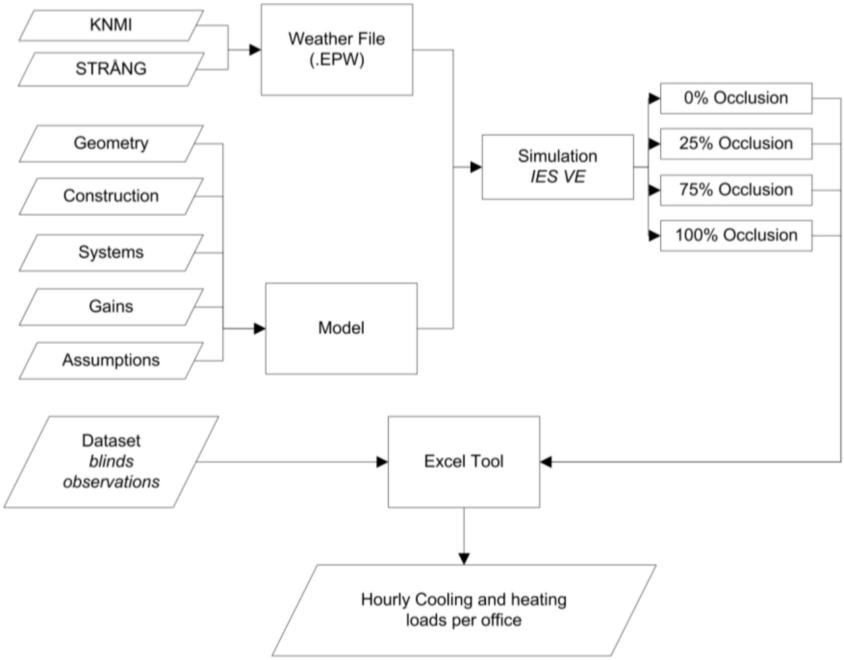


Figure 32 Schematic overview of simulation method

6.2.2 Dataset blinds observations

The results of the field study revealed four different types of blinds users, clustered based on their frequency of manual blinds adjustments and the ratio between system-triggered and user-triggered adjustments (see Figure 31). These four were: C1 – few adjustments, mostly user-triggered (about 20% of offices); C2 – average adjustments, mostly user triggered (about 30% of offices); C3 – many adjustments, mostly user-triggered (about 20% of offices); C4 – system control with manual override (about 25% of users). Five offices could not be categorized into one of the four clusters and were left out of the energy simulation described in the next section. The dataset consisted of a list of the blinds occlusion levels (0%, 25%, 75%, 100%) for each of the 35 offices for every 15 minutes on working days with the first measurement point at 8:15 and the last at 17:45.

6.2.3 Weather data

Table 39 shows the weather parameters that were imported to the IES VE simulation software in an Energy Plus weather file. Most weather parameters were collected from a weather station of the KNMI (Royal Dutch Meteorological Institute) at the Eindhoven airport, 6.6km from the building of the field study: the outdoor temperature, dew point temperature, relative humidity, atmospheric pressure, wind direction and speed, and cloud cover. Solar irradiation values were collected from STRÅNG (Carlund, 2011). The STRÅNG model produces values of global radiation, direct normal radiation, and sunshine duration at a horizontal resolution of approximately 11 x 11 km and a temporal resolution of one hour. Global horizontal irradiance is the total amount of shortwave radiation received from above by a horizontal surface. Direct normal irradiance is the amount of solar radiation received per unit area by a surface that is perpendicular to the rays that come in a straight line from the sun at its current position in the sky. Diffuse horizontal irradiance is the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.

6.2.4 Building model

The building consisted of a concrete structure and the floors were created by concrete hollow-core slabs. The façade was formed by an uninsulated inner and outer leaf made of concrete. At the inside, the ceiling was constructed with a suspended ceiling and the inner walls were formed by metal studs and a gypsum layer. The floors were finished with carpet. The offices were designed to occupy two employees but the actual occupancy fluctuated between different offices and throughout the day. A model office room was constructed based on the information from the building specifications and building management system. An overview of the most important parameters of the model including room and window dimensions, U-values, and heating and cooling set points is shown in Table 40. The heating and cooling system used set points that varied over the day. For example, after 18:00 hour the heating was switched on when room temperature fell below 16˚C, while between 07:30 and 18:00 it was switched on when room temperature dropped below 20˚C.

Table 39 Weather parameters included in the simulation

Parameters	Units	Source	Measurement
Temperature	˚C	KNMI	Timed
Dew point temperature	˚C	KNMI	Timed
Relative humidity	%	KNMI	Timed
Atmospheric pressure	hPa	KNMI	Timed
Global horizontal solar irradiation	W/m^2	STRÅNG	Timed
Direct normal solar irradiation	W/m^2	STRÅNG	Timed
Diffuse horizontal solar irradiation	W/m^2	STRÅNG	Timed
Wind direction	°	KNMI	Hourly average
Wind speed	m/s	KNMI	Last 10 min. average
Cloud cover	Oktas	KNMI	Timed

Table 40 Parameters and values used in the modelled office

	Parameter	Value
Office dimensions	Length x width x height	6.44 x 3.86 x 3.35 m
Window dimensions	Base height	0.85 m
	Height	2.40 m
	Width	3.30 m
Thermal constructions	Internal walls (U-value)	2.878 W/m²·K
	External wall (U-value)	1.552 W/m²·K
	Glass (U-value)	1.185 W/m²·K
	Ceiling (U-value)	1.796 W/m²·K
	Floor (U-value)	1.796 W/m²·K
Thermal system	Heating set point	0:00-7:30: linearly increasing from 16°C to 20°C 7:31-18:00: 20°C 18:01-23:59: linearly decreasing from 20°C to 16°C
	Cooling set point (only if office is occupied)	0:00-7:30: linearly decreasing from 28°C to 23°C 7:31-18:00: 23°C 18:01-23:59: linearly increasing from 23°C to 28°C
Ventilation	Air exchange per hour	1.5

The internal heat gain caused by sources inside the office was another factor included in the model. The following assumptions were made to simulate the internal heat gains. First, when fully occupied an office contained 2 persons with a gain of 90 W per person. Furthermore, for electrical equipment (computers, mobile devices, etc.) an internal heat gain of 300 W was assumed with 2 persons in the office. Finally, internal gains for the lighting were estimated. Four ceiling lighting fixtures (TL5 54W fluorescent lights were controlled by presence sensors (on/off) and two of those by daylight linked dimming. Because no occupancy data and dim levels were available, the total heat gain from the four light sources was estimated to be 120 W, based on a heat gain of 70% (30% visible radiation), which is considered normal for fluorescent lighting, and an assumed average dim level of 80% throughout the working day.

6.2.5 Assumptions

For the simulations, a number of assumptions had to be made in addition to the ones mentioned before. First, it was assumed that each office was occupied by two persons, while in reality some offices were occupied by three persons. Since the occupancy was not monitored, it was assumed that the offices were 100% occupied. Furthermore, it was assumed that the door was always closed and therefore no additional ventilation or heat gain by opening of doors was modelled.

6.3 Results

Figure 35 shows the average heating and cooling load (W) and outside temperature per office for user group C1-C4 on each workday (8:15-17:45) during the trial period. The average cooling load for user group C4 (auto mode) was generally lower than for the user groups that switched off the automatic mode (C1-C3). However, in November and December with lower outside temperatures, the manual user groups (C1-C3) generally had lower heating loads than the automatic mode group (C4).

Figure 33 shows the average heating and cooling load (W) per office on a workday in correlation with the daily average outside temperature for the four different user groups. The scatterplots indicate that in particular with higher outside temperatures, the load in the groups C1-C3 was higher than in group C4. For each group, a polynomial regression analysis was conducted to model the average load (P) as a function of the outside temperature (t), resulting in the following equations:

$$P_{c1} = 535.1 - 93.61\ t + 4.075\ t^2 \qquad (R^2=54.9\%)$$

$$P_{c2} = 481.6 - 82.83\ t + 3.501\ t^2 \qquad (R^2=64.4\%)$$

$$P_{c3} = 401.4 - 68.25\ t + 2.839\ t^2 \qquad (R^2=69.3\%)$$

$$P_{c4} = 346.5 - 49.45\ t + 1.709\ t^2 \qquad (R^2=62.7\%)$$

The average heating load per office on a working day for users of the automatic mode was not significantly different from the average heating load for the three groups of manual users (23.3W versus 16.5W; T=0.96, p=0.338). However, the average cooling load per office on a working day for users of the automatic mode was significantly lower than for the three groups of manual users (19.7W vs. 112.0W; T=-5.49, p=0.000). Also the combined average load for heating and cooling per office on a working day was significantly lower for the automatic mode than for the three groups of manual users (43.0W vs. 129.0W; T=-4.99, p=0.000). Figure 34 shows the average combined heating and cooling load per office on workdays during the trial for user group C1 to C4. The bars represents the 95% confidence interval. The average load in C1 (few adjustments, mostly user-triggered) was 3.8 times higher than in C4 (system control with manual override). The average load for the most active user control group C3 was almost 40% lower than the average load for the least active user control group C1, but still 2.3 times higher than for automatic mode users C4.

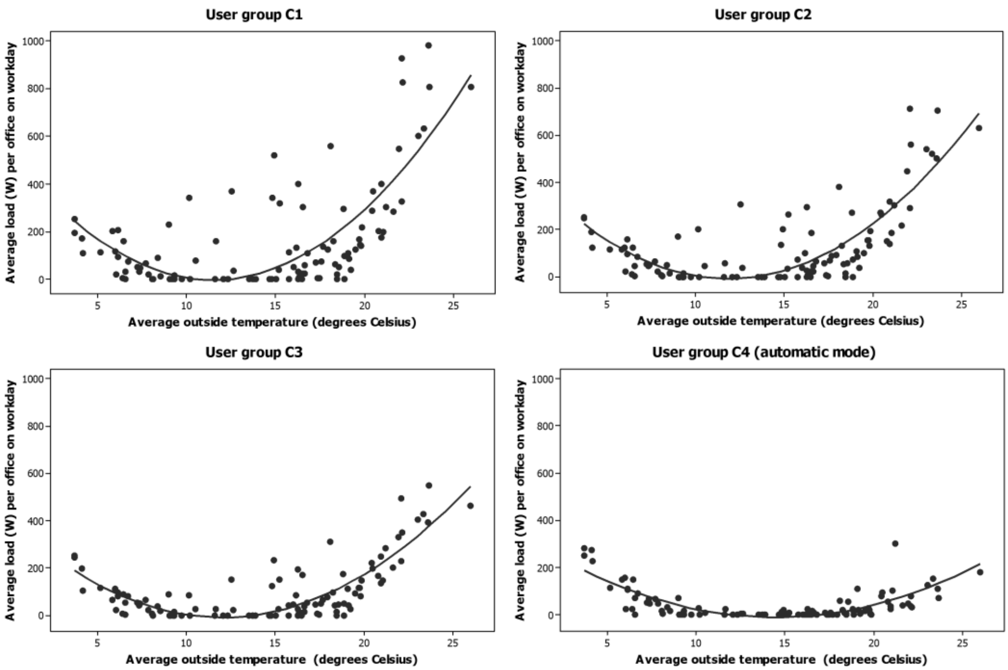


Figure 33 Scatterplots of the average outside temperature (° Celsius) versus the average load for heating and cooling (W) per office on workdays for user group C1 – C4.

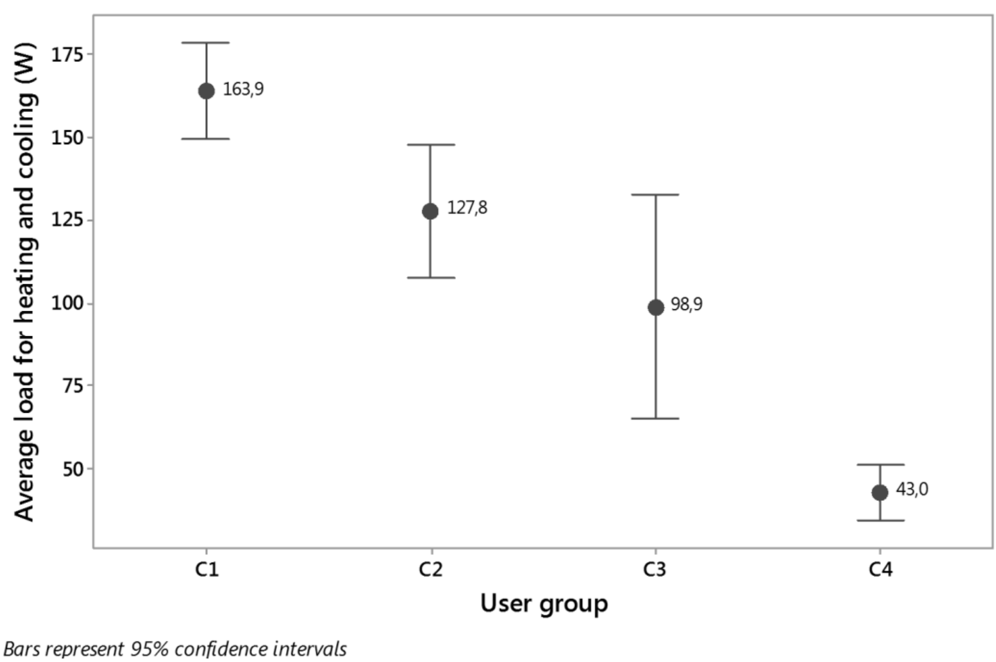


Figure 34 Average load for heating and cooling (W) per office on a workday per user group (average of all working days of the trial period)

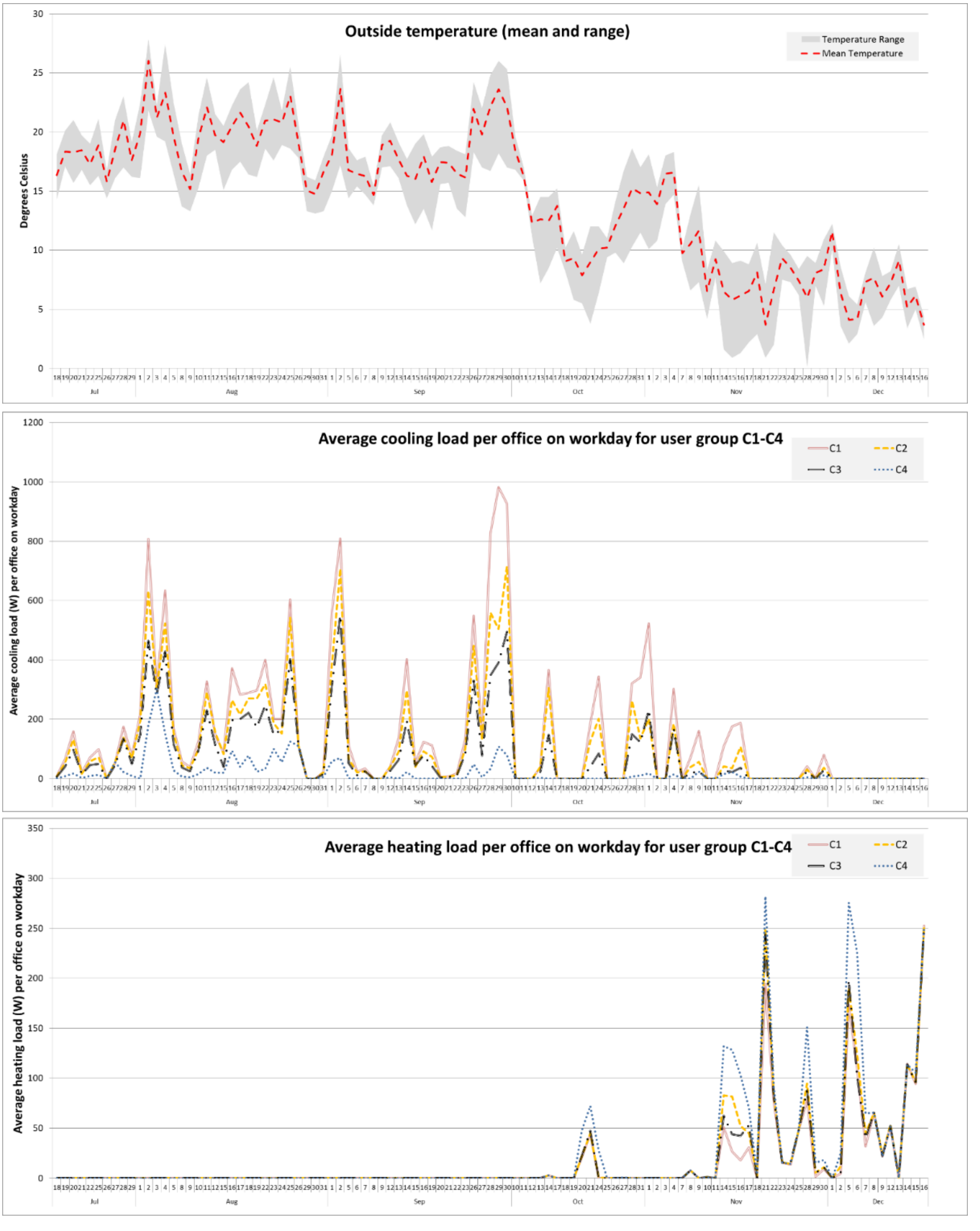


Figure 35 Outside temperature (top), average cooling load (centre) and heating load (bottom) per office on workdays during the trial

6.4 Discussion

An interesting and striking result of the field study reported in Chapter 5 was that a majority of the building occupants switched off the automatic mode of the blinds system permanently. The simulation results indicate that the average heating and cooling load for users that use the automatic mode are lower than for people that switched off the automatic mode. In particular, much more energy for cooling was needed in the offices that did not use the automatic mode. This can be explained by the fact that the blinds for automatic mode users were down more often. Especially, with higher outside temperature and increased solar heat gain, the difference increased. In November and December with lower outside temperatures, the manual user groups on average had lower heating loads than the automatic mode group, although not significant. This can be explained by the fact that the automatic mode users made less use of the solar heat gain, as their blinds were more frequently lowered, while people who switched off the automatic mode used the solar heat gain in winter and needed less energy for heating their room.

The simulations were performed with a number of assumptions and limitations that introduce uncertainty and potential errors in the results. Therefore, the findings, and in particular the absolute numbers regarding the heating and cooling loads, should be taken with care. Nevertheless, the relative differences in heating and cooling loads between different types of blinds users are interesting results and clearly indicate the negative consequences of switching off the automatic mode on energy consumption. Further studies are recommended to validate the results of this study. It is outside the scope of this work to specify the uncertainty levels introduced by the various parameters and indicate the error margins, but the main factors that might have impacted the generalizability and reliability of the simulation results will be described next.

With a large field study it is impossible to control for all variables and there are restrictions on the data that can be collected. Although the field study was one of the few large scale long-term studies on this topic, it still only involved one particular building at one particular location. Furthermore, one specific shading solution was used: automated exterior blinds (triggering at 16klx at the rooftop sensor) with opt-out option and manual override in combination with manual interior roller shades. Due to technical and practical feasibility, only the exterior blinds usage was monitored with an accuracy of about 90%. The usage of interior shades might have been a confounding factor that was not measured throughout the field study. It is recommended to repeat this type of field studies in different settings with different blinds systems and algorithms. Moreover, no occupancy measures could be taken, as for privacy reasons this would require asking all building occupants for their consent to participate in the trial. However, the authors did not want to inform the occupants that they were part of the study, as this might have altered their blinds usage. Due to the absence of occupancy data, a 100% occupancy was assumed for the simulations which is not realistic.

Regarding the simulation results, it is important to mention that only the heating and cooling loads are included. Although this is the most substantial part of the total energy consumption, other energy consumption aspects including energy for electric lighting and for driving the motors of the exterior blinds are not included in the simulations. Moreover, assumptions had to be made that limit the generalizability of the results. The most important assumptions are related to the specific building construction (e.g. U-values), sources of internal heat gain, and thermostat control for heating. In reality, occupants could influence the room temperature with a thermostatic radiator valve by a rotating a dial between 0 (no flow of hot water) and 5 (max flow of hot water). Since the thermostatic radiator valve could not be monitored during the field trial, it was assumed for the simulations that it was in position 3. Also the assumption of 100% occupancy limits the generalizability and reliability of the results. From an online questionnaire among the building occupants (N=71) prior to the field study, 60% of the occupants indicate to spend between 50-75% of their working time behind their desk, while 32% of the occupants spend 75-100% of the time behind their desk. Assuming two occupants per office, this would mean that in approximately 10% of the time nobody is in the room. In this case, the cooling set point of 24° Celsius would be deactivated, allowing room temperatures up to 28°. Also, the internal heat gain from the human body would be absent. So in practice, the energy consumption levels for cooling would most likely be slightly lower with lower occupancy. Although the heating set point was not connected to the occupancy of the room, a lower occupancy level would most likely result in slightly higher energy consumption for heating as there is no internal heat gain from persons in the room. Although it would have been reasonable to assume an occupancy level of around 90%, it was decided to assume 100% occupancy for the simulation, because it was unknown which offices were unoccupied. This could further decrease the reliability of the simulations. Another factor that potentially reduces the reliability of the simulation results is the resolution of the measurements. The blinds occlusion levels were recorded every 6 minutes and grouped in four categories (0%, 25%, 75%, or 100% occlusion). In reality blinds could (although not very likely) move up and down within the 6 minutes time interval and the occlusion level could be any value between 0 and 100%. Furthermore, the weather data were collected at a weather station 6.6 km from the office building and the sunshine radiation data at a resolution of 11 x 11 km. This is an approximation of the real weather conditions at the exact location of the building.

6.5 Conclusions

To conclude, this chapter reported a study on the impact of different usage patterns of an automated blinds system on the energy consumption for heating and cooling in a Dutch office building. A five-month observational field study in 40 offices resulted in a dataset on the blinds usage of four types of blinds users (Chapter 5). This dataset was used to simulate the effect of the blinds usage on heating and cooling loads. Although several assumptions were made that limit the reliability and generalizability of the results and possibly introduce errors, the simulations provide strong indications that the blinds usage pattern has a significant impact on the energy consumption in office buildings. The average load for heating and cooling per office on a working day was significantly lower for the automatic mode than for the three groups of manual users (43.0W versus 129.0W; $T=-4.99$, $p=0.000$). Hence, it seems problematic from an energy saving perspective that a large majority of users switches off the automatic mode of an exterior blinds system. Further research is needed in other buildings, settings, and regions to increase the understanding and evidence about the impact of blinds usage on energy consumption. Furthermore, it seems worthwhile to investigate ways for improving the acceptance of automated blinds systems; not only for increased comfort of the building occupants, but also for a reduction of the energy consumption in buildings. One direction is the design of intelligent systems and improved algorithms that better match with personal comfort desires of building occupants, for example through self-learning systems. Another promising direction could be to make building occupants more aware of the way blinds systems work and their impact on the energy consumption in a building. If the automatic blinds system communicates to users about its automatic blinds adjustments, this could increase the acceptance of automatic blind changes.

7 Design of Automated Blinds personality and behaviour

Office buildings are gradually becoming smart environments and today simple forms of building automation such as automated blinds are already common practice. Similar to the automated behaviour of domestic robots described in the first part of this thesis, the autonomous behaviour of blinds might cause people to attribute a personality to the system. If this is true, what kind of personality would be desirable? The design process as presented in Chapter 2 was applied to the design of an automated blinds system. A workshop was organized to create a desired personality profile and corresponding behaviour for the automated blinds system. Based the workshop results, an ambient light feedback device was designed and integrated into the blinds to provide users with information on the daylight conditions outside and upcoming or recommended blind changes.

This chapter is partly based on the following publication:

Meerbeek, B., de Bakker, C., de Kort, Y., van Loenen, E., & Bergman, T. (2016). Automated blinds with light feedback to increase occupant satisfaction and energy saving. *Building and Environment, 103*, 70–85

7.1 Introduction

As explained in Chapter 5, buildings are gradually becoming smart environments and first simple forms of building intelligence such as occupancy sensing or daylight-based dimming are already common practice. Similar to the automated behaviour of domestic robots described in the first part of this thesis, autonomous behaviour of buildings might cause people to attribute a personality or human-like traits to a building. Although at first it might seem awkward to talk about the personality of a building, it is not uncommon in architecture to attribute a personality or character to a building. The famous Swiss-French architect and pioneer of modern architecture Charles-Édouard Jeanneret-Gris (Le Corbusier) stated that "*Every building should have a character.*" He was one of the first to apply anthropomorphism to architecture and to design, for example, masculine and feminine building elements. He used colours, sounds, and senses of touch to give a building character, for example in the Philips Pavilion designed for the Expo '58 (Figure 36). Both the outside appearance with its remarkable geometry and the interior including a multimedia experience make the building express a distinctive character that is definitely not introvert, calm, or boring. Alan de Botton, author of the 'The Architecture of Happiness', introduced the term 'talking building' referring to how "arrangements of stone, steel, concrete, wood, and glass seem able to express themselves […] and leave us under the impression that they are talking to us about significant and touching things." (De Botton, 2006). He explains that people do not need much to interpret furniture or buildings as objects with a character. Even the smallest features in a building can help people judge its personality (Figure 36). De Botton explains that this personality attribution is often driven by associations that are evoked by particular elements of the building based on people's previous experiences. He also states that there is no dictionary or common language yet in architecture to describe what building elements express. In this chapter, the vocabulary to describe human personality (John & Srivastava, 1999) is used to define the character of buildings, more specifically the personality of an automated blinds system.

If people indeed perceive automated blinds to have certain personality, questions arise what kind of personality the system should have, how it can be expressed in its behaviour, and how it can help occupants to interact with the intelligent system. Building further on the work from Chapters 5 and 6, the focus of Chapter 7 is on the design of personality and behaviour for an automated blinds system using the design process as described in chapter 2.

Figure 36 Left: Philips Pavilion at Expo'58 with a distinctive character ((Hagens, 2015)). Right: Example of a fanlight window that promises playfulness and courtesy (source: (De Botton, 2006))

7.2 Create personality profile

7.2.1 Workshop 'Building with character'

As a first step to come to a desired personality and behaviour for ambient intelligent environments, and more specifically an automated blinds system, a workshop "Building with Character" was organized. The goal of the workshop was to create a desired personality profile for an automated blinds system. Professionals with a variety of relevant backgrounds were invited to participate. The five participants had a background in human-computer interaction, architecture and the built environment, industrial design, smart lighting, and user-system interaction.

At the start of the workshop, the rationale for designing intelligent buildings with a personality and relevant background information were provided and discussed within the group of participants. A few interesting points were raised during the discussion. For example, the belief that the character of a building depends on many more aspects than the behaviour of the smart building system, including the context of the building, its inhabitants, and the activities that take place in the building. One participant posed the question why a building could not just have one similar positive character, as nobody wants to have a building with a negative character. A 'butler' was mentioned as a nice metaphor for the desired personality of a smart building. It shows intelligent behaviour without the need for explicit instructions and explanations. Another topic that was raised during the workshop was trust. Trust was considered important in intelligent buildings and related to loyalty of its inhabitants and forgiveness if the building system makes a mistake. Participants mentioned that some brands like Apple, IKEA, and LEGO are trustworthy. These brands have built up this trust over a longer period of time.

As a next step, the workshop participants were asked to read a user profile description that was generated based on the results of the field study reported in Chapter 5 to understand the needs and desires of the target user group:

> *As an office worker, I spend a significant amount of time at my work place. Therefore, I find it important to have comfortable working conditions that allow me to work effectively and make me feel well. I'm pretty sure that things like the temperature, the noise, and the lighting conditions in the work environment have an effect on the way I feel and on my performance.*
>
> *I spend a significant amount of time in the office, so it is important that I feel well in my work environment. If I can choose, I prefer to sit close to a window. I like to work in daylight and have a view and connection to the outside world.*
>
> *One of the problems at my current work place is the automatic blind system. I'm not sure how it exactly works, but often the blinds are lowered at moments I don't want - taking away my view and daylight. The automatic adjustments at the wrong moments annoyed me and I switched off the automatic mode. I rather control it myself, although I realize that this takes some effort.*
>
> *To be honest, I don't adjust the blinds very often. If the sun is bothering me too much, I'll lower the blinds. But often I forget the raise them again. Then I suddenly realize that they are still lowered and put them up again.*

To guide the discussion on the desired personality of the automated blind system, a selection of personality traits from the Big-Five personality inventory was presented. The same traits were used as with the creation of the robot vacuum cleaner personality in Chapter 3, see Table 41. Participants were asked to discuss each trait and decide whether it was a desired characteristic for an automated blinds system. The moderator took notes to capture the discussion. In the next sections the results of the discussion are summarized.

Table 41 Selection of Big-Five personality traits used in workshop 'Building with Character'

Dimension	Positive items	Negative items
Extraversion	Energetic Talkative	Reserved Withdrawn
Agreeableness	Polite Cooperative	Bold Distant
Conscientiousness	Systematic Efficient	Careless Spontaneous
Neuroticism	Easily discouraged Moody	Relaxed Calm
Openness to experiences	Creative Curious	Superficial Likes routines

7.2.2 Non-desirable personality traits

The following traits were considered not desirable for an automated blinds system: energetic, talkative, reserved, withdrawn, distant, systematic, careless, spontaneous, moody, relaxed, and superficial.

'Energetic' was associated with rapid changes and therefore not desired. The system can be energetic when the user is not in, but if there is a blind change initiated by the system, it should do it slow and calm not to annoy the user. However, if a user triggers a change of the blinds, the system should act more energetically and swiftly. As users might want to know why blinds are going up or down, being 'talkative' might be a desirable trait. However, too many interruptions would be annoying for the office worker. It could be fun if the system would be talkative, but it would be more desirable if users can ask the system for information. It was considered not desirable to have a 'reserved' system. The system should take initiative. Also 'withdrawn' was considered not desirable. This was associated with being sneaky and doing things when the user is not present. 'Withdrawn' was also associated with being an indifferent bystander who does not care. The system should be more attentive, like a good waiter in a restaurant. Being 'distant' was associated with a system that is not listening and not really present, perhaps even imaginary, and therefore not desirable. 'Systematic' was associated with logical, rule-based, predictable, and less flexible behaviour. It was associated with an inside-out perspective of the system, missing contextual awareness and reasoning from the system point of view. Hence, systematic was also selected as a non-desirable trait. Also being 'careless', 'moody', and 'superficial' were clearly undesirable characteristics. 'Spontaneous' was considered conflicting with predictability and therefore not desirable. Finally, also 'relaxed' was not desirable as it was associated with not working hard and being lazy.

For a few personality traits, participants were indifferent or could not make a decision whether it was desirable or not. This included 'bold' and 'likes routines'. Participants indicated that the blinds system should dare to make decisions, but it could be annoying if it is too bold. Some participants considered 'like routines' desirable, as this could imply always starting at the same position in the morning. This makes the system behaviour predictable. On the other hand, this might not be desirable behaviour in more open and flexible workspaces. In these situations, it would be good if the system is more eager to learn new routines.

7.2.3 Desirable personality traits

The following traits were selected as desirable for an automated blinds system: polite, cooperative, efficient, easily discouraged, calm, creative, and curious. In addition, participants suggested the following characteristics as being desirable:

predictable, swift response, flexible, in the background, courage to take decisions, and attentive.

'Polite' was a desirable characteristic. The system could politely inform users why blinds go up and down. Proper timing of communication is important. It should notice when you are in a conversation or doing work that requires concentration and when not to disturb you. Also, 'cooperative' and 'calm' were undoubtedly selected as desirable characteristics. 'Efficient' was also considered desirable, although more in terms of efficient in realizing a comfortable work environment for people than only efficient in terms of energy saving.

While in human personality, being 'easily discouraged' is mostly considered an undesirable trait, for the automated blinds system it was considered desirable if the system is easily discouraged by the user. This refers to the automatic system being easily overruled by a user. For example, if a user gazes slightly annoyed at the blinds when it starts to retract, the system gets discouraged and stops retracting the blinds. However, being easily discouraged should not result in a doubtful system that does not know whether it should move up or down.

The automatic blinds system should also be 'creative'. Creativity was considered the top of intelligence by the workshop participants. The system should be able to learn and find creative solutions. Also, 'curious' is a desirable trait and was associated with contextual awareness and learning capabilities. For example, curious in learning how to better satisfy the user needs or learning from other blinds.

7.2.4 Discussion and conclusions

Interestingly, all positive and negative items on the extraversion scale were considered not desirable for an automated blinds system suggesting it should neither be extravert nor introvert. While energetic and talkative were considered 'too much' for an automated blinds system, the participants did not appreciate a reserved and withdrawn system either. A more balanced personality seemed to be preferred by participants, as also illustrated by their metaphors of a waiter who is working quietly in the background without disturbing your dinner experience, while at the same time being attentive and responsive if you need him. On the agreeableness dimension, participants clearly expressed a preference for the positive items (cooperative and polite). Friendly behaviour and communication of the system towards the user is desirable. Imagine yourself sitting in your office enjoying a lovely view and the daylight. Suddenly, a man walks into your office, and without saying a word, he walks to the window, lowers your blinds and walks out again. This would be considered impolite and unacceptable behaviour, so why would you accept it from an automated blinds system? On the conscientiousness dimension, the negative items ('spontaneous', 'careless') are not desirable for an automated blinds system, but also systematic was undesirable as it was considered too rigid. There is a clear desire for a predictable but flexible behaviour of the automated blinds system. On the neuroticism dimension, a 'calm' personality is desired. 'Relaxed' however was considered too strong and undesirable. And finally, on the 'openness to new experiences' dimension, 'creative' and 'curious' are desirable personality traits for an automated blinds system. These are considered important elements of real intelligent behaviour.

7.3 Expressing personality in behaviour

Based on the selected set of desirable personality traits, the workshop participants generated ideas on how this personality could be expressed in the automated blinds system behaviour. Several ideas were generated and clustered in more abstract system behaviours after the workshop. To a large extent, these ideas could be clustered into the five key characteristics of Ambient Intelligent systems as described by (Aarts & Marzano, 2003): embedded, context aware, personalized, adaptive, and anticipatory. However, there were also ideas that were specifically about the expressivity of the system by giving feedback and feedforward information.

Embedded refers to the integration of technology into the environment and an ecosystem of networked devices. Ideas were expressed to integrate sensing and feedback elements in the blinds and let the system work in the background ('ambient'). Also, several ideas were mentioned about connecting the blinds system with people's agenda information, the lighting system, the heating and cooling system, and other blind systems.

Several ideas around context-awareness - devices that can recognize users and their situational context - were mentioned. For example, the blinds system would perform the blind adaptations preferably when occupants are out of office to reduce disturbance. Although in case of a disturbing glare situation, it should act immediately and not wait for the person to leave the room. Another idea was a blinds system that takes into account cues in the environment such as people moving around or having conversations to decide the most optimal moment of changing the blinds.

Personalized refers to a system that can be tailored to your needs on a short term scale. For example, a first time configuration in which users can express their preference with respect to daylight, temperature, and blinds. This allows the system to quickly learn user preferences.

Adaptive refers to a system that monitors the users and changes in response to their behaviour. There were several ideas on easy ways for users to overrule the system and adapt its behaviour. For example, an automated blinds system that - when starting a blind adjustment - would recognize if a user is distracted or annoyed and then cancels the blinds change. Detecting users gazing towards the system and their facial expression (e.g. angry, annoyed) or detecting specific gestures were mentioned as possible solutions.

Anticipatory refers to a system that can anticipate users' desires without conscious efforts from the user. The systems knows the user based on a long-term relationship and detected user behaviour. An idea in this category was a blinds system that would learn from implicit and explicit user feedback and manual blind adjustments to learn users' preferences. Another idea was to use the weather forecast to anticipate changing circumstances and adapt the blinds more gradually to meet the user needs.

There were several ideas that went beyond the five key elements of Ambient Intelligent system. These ideas all related to communication between the blinds system and the user. One idea was to visualize the energy usage through light feedback integrated in the blinds. Also, participants mentioned the idea to visualize the intended blinds changes so users can anticipate a change and accept or reject it. Another idea was to provide on-demand information about the reasons for particular blind adjustments initiated by the system.

7.4 Specify design rules

Given the scope of this thesis, it was decided to focus on designing the expressive behaviour of the blinds system to communicate its status and intentions to occupants, while keeping the basic functional behaviour comparable to the automated blinds systems as presented in Chapter 5.

Based on the user study results reported in Chapter 5 and the results of the workshop reported in this chapter, the feedback mechanism should be 'ambient' and embedded in the built environment informing users in an unobtrusive way. This is considered an important quality of the system, since office workers expect it to work quietly in the background without disturbing them, while at the same time being attentive and responsive to their needs. Previous work has reported various examples of ambient information systems that have been developed for other domains using displays, sounds, everyday objects, or art pieces to inform the user (Pousman & Stasko, 2006). In this study, we explore the use of a lighting device embedded in the blinds to communicate to users about its' status and intentions. Light is a medium that can be directed and can easily move from the centre of our attention to the periphery and back again which makes it a suitable modality to provide ambient information (Aliakseyeu, Meerbeek, Mason, Magielse, & Seitinger, 2016).

The ambient light feedback device should provide information to users on the actual outside daylight conditions that trigger automatic blind changes and about upcoming or recommended blind changes to increase the predictability of the system. The provisioning of information and enhanced predictably are expected to contribute to increased perception of control and higher satisfaction with the automated blind system (Skinner, 1996). Moreover, in an earlier study ambient light feedback was found effective in influencing users' behaviour (Maan, Merkus, Ham, & Midden, 2011). The authors tested the effect of feedback provided by a lighting device that gradually changed its colour dependent on energy consumption and compared it with the effect of numerical feedback. The ambient light feedback was found to have stronger persuasive effects. Hence, it is expected that the expressive interface not only contributes to a higher perception of control and increased user satisfaction, but also affects the actual blinds usage. These expectations are tested with the studies described in Chapter 8.

7.5 Implement behaviour

The light feedback system was designed to be mounted on top of a motorized blind system installed in front of a virtual window. It consists of a pixelated LED strip with individually controllable LEDs. On top of this LED strip, a transparent light guide panel (Evonik EndLighten ™) was placed such that the light from the LED strip coupled into the side of this light guide material. The light guide diffuses the light and couples it out sideways such that an evenly illuminated panel is created. Laser cuts were made in the light guide panel and acted as mirrors due to total internal reflection (TIR) of the light, resulting optically in twelve individually addressable light segments. The ten segments in the centre form the blocks that indicate the level of solar radiation, ranging from level 1 (low radiation) to level 10 (high radiation), while the two segments on the sides are shaped as an arrow up and an arrow down to indicate the recommended or effectuated blind change (Figure 37). Each of these segments can be switched on and off separately by controlling the underlying LEDs independently. In on state, the segment takes the colour of the LEDs that couple the light into it, and in off state the segments become transparent and practically invisible. The behaviour of the light feedback system was programmed with Arduino.

Two variants of the ambient light feedback were designed. In version A, the system expressed its intentions with a gradual colour change of the arrows, starting from green and changing to red to indicate a higher urgency for adjusting the blinds. In version B, the arrows were red and pulsating at increasing rate to indicate an increasing urgency to adjust the blinds. The arrows increased their pulsing rate in three steps. First, the arrows were on for 1 second and off for 1 second, so a pulsing rate of 0.5 Hz. The pulsing rate then increased to successively 1 Hz and 2 Hz.

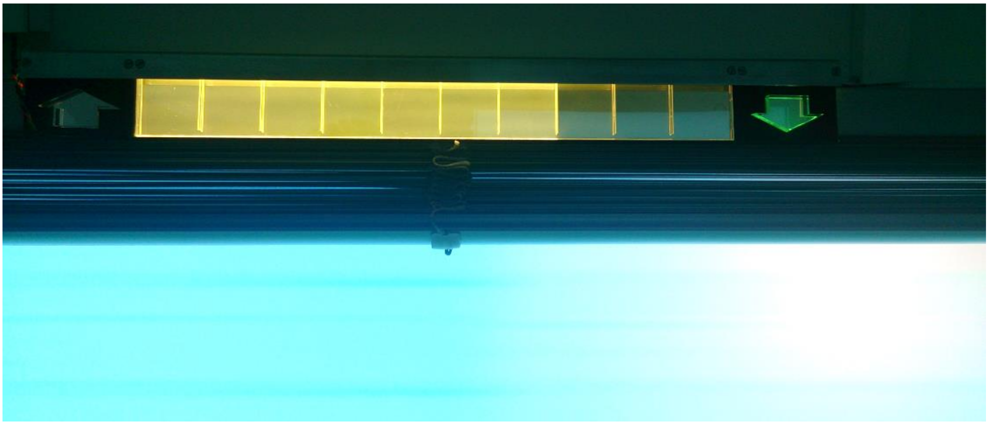


Figure 37 Light feedback system mounted on top of a motorized blinds system in front of a virtual window

7.6 Evaluate behaviour

The ambient light feedback device for the automated blind system was evaluated in two user studies with two types of expressivity and three levels of automation (low vs medium vs high) to evaluate the impact of these design parameters on the perceived system personality, perceived level of control, user satisfaction and usage of the blinds system. These studies are presented in Chapter 8.

7.7 Discussion and conclusions

The design process as described in Chapter 2 focused on the development of personality and behaviour for a domestic robot. In this chapter, a similar process has been applied to the development of an automated blinds system. Although most people would not classify an automated blinds system as a robot, it has many of the characteristics that are generally attributed to robots. The blinds have a motor to automatically move up and down, sense and manipulate the environment, and show some degree of autonomous behaviour. Therefore, it was assumed that similar processes of animacy and personality attribution would occur for these type of systems and the proposed design process of Chapter 2 could also be applied to define the personality and behaviour of an automated blinds system.

During the workshop to create a personality profile, participants were first struggling to think about a desired personality for something mundane like a blinds system. But soon, the cards with human personality traits proved to be fun and helpful instruments to discuss the desired behaviour of an automated blinds system and sparked the creativity to come up with concrete ideas.

Table 42 shows the various personality traits and their desirability as indicated by the workshop participants. According to the participants, the automated blinds system should not be energetic, talkative, reserved, withdrawn, distant, systematic, careless, spontaneous, moody, relaxed, and superficial. It should be polite, cooperative, efficient, easily discouraged, calm, creative, and curious. In addition, participants indicated that the automated blinds system should have the following characteristics: predictable, swift response, flexible, in the background, courage to take decisions, and attentive.

Ideas on how this personality could be expressed in the behaviour of the automated blinds system were generated and clustered into the five key characteristics of Ambient Intelligent systems: embedded, context aware, personalized, adaptive, and anticipatory. An additional cluster of ideas was identified, specifically about the expressivity of the system by giving feedback and feedforward information. These ideas were developed further and implemented as a light feedback device embedded in the blinds system. This ambient light feedback device was designed to provide users with information on the actual outside daylight conditions and about upcoming or recommended blind changes to increase the predictability of the system. A detailed evaluation of this system is presented in Chapter 8.

Table 42 Desirability of personality traits for automated blinds as indicated by participants

Personality dimension	Personality trait	Not desired	Neutral	Desired
Extraversion	Withdrawn (-)	X		
	Energetic	X		
	Talkative	X		
	Reserved (-)	X		
Agreeableness	Cooperative			X
	Distant (-)	X		
	Bold (-)		X	
	Polite			X
Conscientiousness	Efficient			X
	Spontaneous (-)	X		
	Careless (-)	X		
	Systematic	X		
Neuroticism	Moody	X		
	Easily discouraged			X
	Calm (-)			X
	Relaxed (-)	X		
Openness to new experiences	Likes routines (-)		X	
	Curious			X
	Superficial (-)	X		
	Creative			X

It should be noted that our workshop on automated blinds with a personality was held with only five participants who were invited for their professional expertise on designing intelligent systems. So in contrast to the work report in chapter 3 - where we involved end-users of the intelligent system (robotic vacuum cleaners) in the personality design process by asking them about desired system personality - we involved a group of creative professionals who were trained and experienced to represent the end-user in the design of intelligent systems. Although the participants were carefully selected based on their relevant domain knowledge in architecture, user-system interaction, industrial design, and smart lighting, they were not a representative group of automated blinds users. Therefore, one should be careful with the interpretation of the results on the desirability of the personality traits. The results served the purpose of inspiring the design of an expressive interface for the automated blinds system which will be validated in chapter 8, but further validation with a substantial number of end-users would be required to make conclusive statements about the desired personality profile for an automated blinds system.

8 User preferences for automated blinds behaviour

With the increase of building automation in the work environment, there is a risk that occupants lose their sense of control when decisions on environmental aspects such as temperature, electric lighting, and daylight are made by technology. This chapter reports two studies in which we investigated the effect of the level of automation and the type of system expressiveness on users' satisfaction with an automated blinds system installed on a virtual window. An expressive interface was designed to communicate the status and intentions of the blinds system to the building occupants. The results show that the addition of the expressive interface increased user satisfaction compared to the original system. Moreover, users made less corrections after automatic blind adjustments and adherence to the system suggestions increased. These results demonstrate the potential of expressive interfaces to increase user's acceptance of automated blinds and thereby realizing the anticipated energy savings.

This chapter is based on the following publication:

Meerbeek, B., de Bakker, C., de Kort, Y., van Loenen, E., & Bergman, T. (2016). Automated blinds with light feedback to increase occupant satisfaction and energy saving. *Building and Environment, 103*, 70–85

8.1 Introduction

As explained in Chapter 5, the increasing attention for energy efficient buildings combined with technological advances in sensors, processing power, lighting, and networks drive the development of so called 'Smart Buildings'. In such buildings, a balance between energy efficiency and occupant comfort needs to be found, ensuring that people feel comfortable and productive at their workplace while preserving the energy saving potential of building automation technologies. With the increase of building automation in the work environment, there is a risk that occupants lose their sense of control when decisions on environmental aspects such as temperature, electric lighting, and daylight are made by technology.

Previous research on automatic and manual blind systems in the work environment (reported in Chapter 5) indicates the importance of appropriate daylight control for energy saving and user comfort. In Chapter 5, we also reported a field study in 40 Dutch offices in which we monitored the blinds usage of an automated blinds system over a period of 20 weeks. The results showed that a majority of the building occupants (77.5%) switched off the automatic mode of the blinds system permanently. Simulation results in Chapter 6 indicated that this significantly impacts the energy consumption in the building. The estimated total daily average energy consumption for heating and cooling was significantly lower for occupants using the automatic mode than for manual users. One of the reasons for switching off the automatic mode was that the system did not act according to the expectations of the users and occupants did not understand why the blinds were moving up or down. They felt this was often occurring at the wrong moments.

As explained in Chapter 1, appropriate communication from the system towards the users is deemed a crucial factor to help people understand and accept the behaviour of automated systems. This communication might be provided by an expressive interface which provides information to the user about the internal reasoning, intentions, and actions of the automated system.

In this study, we investigate the user satisfaction and actual usage of an automated blinds system with an expressive interface, which was described in more detail in Chapter 7. More specifically, we research the effect of the level automation and the type of system expressiveness on users' satisfaction with and usage of the blinds system installed on a virtual window with LED spot to mimic sunlight. Two studies are conducted to address this research question. In the first study (N=48), three levels of automation and two types of expressiveness are compared in a controlled mixed design user study in a laboratory setting to find their main effects on user satisfaction and blinds usage as well as the interaction effects between level of automation and level of expressiveness (Section 8.3). In the second study (N=24), two types of expressiveness with the same level of automation are compared, again through a user study in a laboratory setting, to zoom in on the effects of the type of expressiveness on satisfaction and usage (Section 8.4). But first, section 8.2 describes the design of the expressive interface and the levels of automation that were tested in these two studies.

8.2 Expressive interface design

8.2.1 Automated blinds system

An automated interior venetian blinds systems was developed with automatic behaviour comparable to the system that was evaluated in the field study report in Chapter 5. In order to test in a controlled setting and not depend on actual variations in daylight conditions, an office environment with a virtual window was created in which daylight situations could be simulated (Mangkuto et al., 2014). Direct sunlight was mimicked with an LED spotlight and its light output thresholds were set as triggers for the blinds system to lower or raise the blinds (described in more detail in section 8.3 and 8.4). The designed light conditions served the main purpose of this study to evaluate various expressive interfaces and automation strategies with the blinds in a relatively short period and in a controlled way, without being dependent on or affected by actual variations in real daylight conditions. The virtual window with an 'outside view' stimulated participants to have the blinds open, while the LED spot was able to create glare and stimulated participants to lower the blinds. It should be noted that the light intensity, spectrum, and glare perception thresholds were specific for the virtual window and LED spot configuration of the two studies and therefore not generalizable to real daylight conditions. For example, it is known that people generally are more tolerant for glare from real daylight with a view than from artificial light sources.

The automated blinds system was extended with an expressive interface to communicate to the users about its' status and intentions. The details of this light feedback system are described in Chapter 7. We designed two variants of the ambient light feedback (moderately expressive and highly expressive) and three levels of automation (low, medium and high) to evaluate the impact of these design parameters on the user satisfaction and usage of the blinds system.

8.2.2 Levels of automation

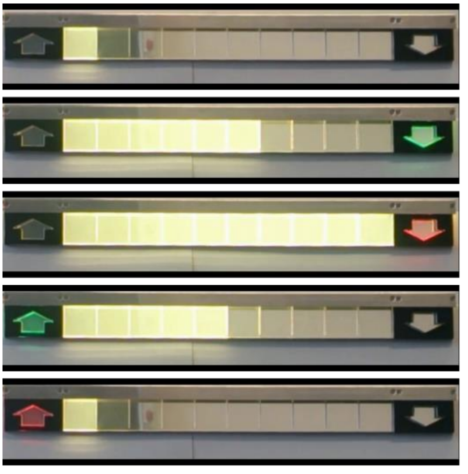
The level of automation was manipulated on three levels varying in decision and action selection in line with the automation scale (Parasuraman et al., 2000). The high level automation was comparable to the systems as investigated in the field study reported in Chapter 5, and can be placed on level 10 on Parasuraman's scale (Table 43) as it does not involve the user in its decision making (although users could overrule its decisions afterwards and have manual control over the blinds). In the medium level of automation, users were able to accept or reject a blinds change suggested by the system (level 6 on Parasuraman's scale). If a user did not act within 50 seconds from the moment a suggestion was made the suggested blinds change would be implemented. The system would approve users' actions if they lowered the blinds to minimally 50% or raised them to minimally 25% and in that case would not undertake further action. In the low level of automation, the system would still suggest a blinds change but users were given the full responsibility to implement the suggested blinds change.

8.2.3 Types of expressiveness

Two types of expressiveness were created. Version A ('gradual') expressed its intentions with a gradual colour change of the arrows, starting from green and changing to red to indicate a higher urgency for adjusting the blinds. Figure 38 shows some examples of the light feedback for Version A at various 'sun light' intensities, suggesting the users to adjust the blinds with the coloured arrows. With version B ('pulsating'), the arrows were red and pulsating at increasing rate to indicate an increasing urgency to adjust the blinds. The arrows increased their pulsing rate in three steps. First, the arrows were on for 1 second and off for 1 second, so a pulsing rate of 0.5 Hz. The pulsing rate then increased to successively 1 Hz and 2 Hz. For the original blinds system (high level of automation) there was no light feedback system.

Table 43 Mapping of levels of automation in Parasuraman's scale to three automation levels in this study (Parasuraman et al.,2000)

	Parasuraman's scale	**Level of automation in this study**
10	System decides everything, acts autonomously, ignoring the human	High
9	System informs the human only if system decides to	
8	System informs the human only if asked	
7	System executes automatically, then necessarily informs the human	
6	System allows the human a restricted time to veto before automatic execution	Medium
5	System executes a suggestion if the human approves	
4	System suggest one alternative	Low
3	System narrows the selection down to a few	
2	System offers a complete set of decision/action alternatives	
1	System offers no assistance; human must take all decisions and actions	



A. Blinds are up, sun level 1

B. Blinds are up, sun level 6: green arrow down to suggest lowering the blinds

C. Blinds are up, sun level 10: red arrow down to suggest lowering the blinds

D. Blinds are down, sun level 5: green arrow up to suggest raising the blinds

E. Blinds are down, sun level 1: red arrow up to suggest raising the blinds

Figure 38 Example of light feedback in different situations

8.3 Study 1: evaluation of light feedback with different levels of automation

8.3.1 Study design

Two levels of automation (low and medium) and two types of expressiveness were combined, which resulted in four different versions of the system. We wanted to compare these versions with the original system (high level of automation without light feedback) as evaluated in the field study reported in Chapter 5, so that it could be investigated whether the light feedback affected users' behaviour and whether these changes indeed improved users' satisfaction. To reduce the length of the experiment it was decided to test the type of expressiveness between subjects and level of automation within subjects. So each participant experienced three versions in a balanced order: the original blinds system without light feedback, and two levels of automation (low and medium) with the same type of expressiveness. Moreover, participants were randomly assigned to the type of expressiveness. The mixed experiment design resulted in the five conditions (C0-C4) presented in Table 44.

Various dependent variables were included in the study design, but in this chapter we only report on the variables relevant to the research question posed in the introduction of this chapter: perceived system personality, perceived control, user satisfaction, and user behaviour. Other variables, including for example perceived ease of use, perceived usefulness, user characteristics, and trust in the system are outside the scope of this chapter.

Table 44 Overview of conditions study 1

	No expressive feedback	Version A (gradual)	Version B (pulsating)
Low automation		C1(A_{low}, E_{grad}) System only suggest; Green-to-red light	C3(A_{low}, E_{puls}) System only suggest; Pulsating red light
Medium automation		C2(A_{med}, E_{grad}) System suggests and acts; Green-to-red light	C4(A_{med}, E_{puls}) System suggests and acts; Pulsating red light
High automation	C0(A_{high}, E_{low}) Original system		

8.3.2 Materials and setting

The study was conducted in the ExperienceLab of Philips Research, which resembled an office setting with a virtual window. An abstract view was created at this virtual window with which we want to give participants the idea of a real view to outside, so they would be motivated to raise the blinds to create an 'outside' view (Mangkuto et al., 2014). The lower part of the window was rendered green to prompt the idea of a meadow and the upper part blue to suggest the idea of a sky. The ceiling lighting fixtures (4000K LED) in the space were set to provide a horizontal illuminance of 300 lx at the desk, which is the minimum for ambient lighting surrounding the task area according to European building regulations (NEN-EN 12464-1). Figure 40 and Figure 41 give an impression of the virtual window, spotlight, and blinds in study 1. A spotlight was used to induce the impression of a sun. At each window, a motorized blinds system (Somfy LW 25 E83 with mat grey-silver coloured slats) was installed covering the full width of the virtual window. Both blinds were controlled simultaneously and could be operated by the experimenter pc (Pharos Designer timelines for automatic blind adjustments) and by the participant via a web interface on a tablet computer.

A light scenario was created to mimic a sun breaking through the clouds and then after a while disappearing behind the clouds again to create situations in which the blinds need to be adjusted. As one of the main reason for users to manually lower the blinds is the prevention of discomfort glare (Meerbeek et al., 2012), we wanted the system to suggest users to lower the blinds before users actually experienced discomfort glare. This would be interesting to investigate, as users were prompted to perform an action while they did not yet feel uncomfortable but that action would be preferred from an energy saving perspective. As the commonly acceptable methods and guidelines for calculating discomfort glare from daylight or electric lighting are not validated for daylight mimicking systems such as virtual windows and existing metrics do not always correlate well to subjective glare perceptions (Mangkuto, 2014), the thresholds for discomfort glare were set based on a few trials with lighting experts evaluating level of discomfort at various light intensities of the sun mimicking spot. The threshold for discomfort glare was consequently set at a vertical illuminance (E_v) of 950 lx at the eye of the participant. The intensity of the spotlight was raised linearly in ten steps from a base level of 470 lx ($E_{v\text{-}min}$) to its maximum of 1230 lx ($E_{v\text{-}max}$), measured at eye height of the participant when seated and also included the lighting provided by the virtual window and the ceiling lights. It should be stressed that these threshold values were determined by subjective evaluations of discomfort glare by a group of lighting experts. These evaluations were not only subjective, but also specific to the experimental setting (participants viewpoint, virtual window, LED spot light, etc.). Therefore, these values cannot be generalized to other real or virtual daylight situations. However, given the main purpose of our study – which is to evaluate the expressive interfaces and automation strategies and not to optimize an automated blind control algorithm - the subjective method was preferred over an objective glare metric. With the chosen thresholds, we were confident that we could create a discomfort glare situation that would trigger participants to use the blinds.

The light scenario was introduced twice per condition, so that users could experience the system behaviour twice, and at different moments, so they would not be able to anticipate on its behaviour. An example test procedure for one condition with two light scenarios is visualized in Figure 39, where the vertical illumination at eye level is plotted over time. The office setting was created by placing two desks perpendicular to the virtual window (see Figure 42). In the back of the lab a group of four more desks was placed. The participant was seated at the desk close to the virtual window that was opposite to the spot light, so that the 'sunlight' was able to create discomfort glare. Participants were able to manually operate the blinds via a tablet. They could adjust the position (0%, 25%, 50%, 75%, and 100%) and the angle of the blinds (horizontal, vertical, 45°) by touching the respective icons on the user interface.

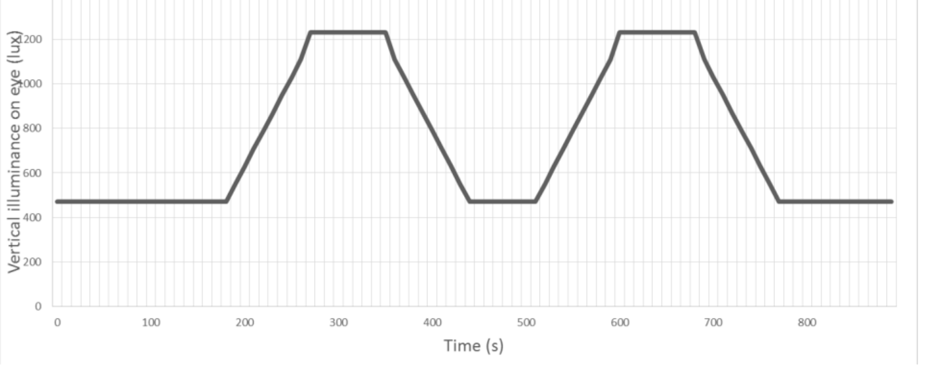


Figure 39 Light scenario of sun-mimicking LED spot light

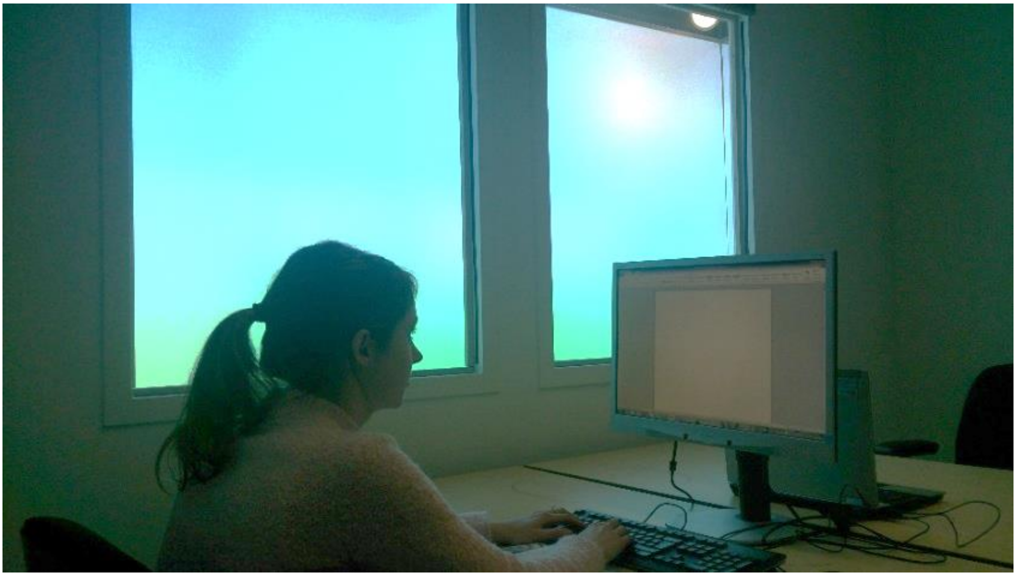


Figure 40 Setting study 1

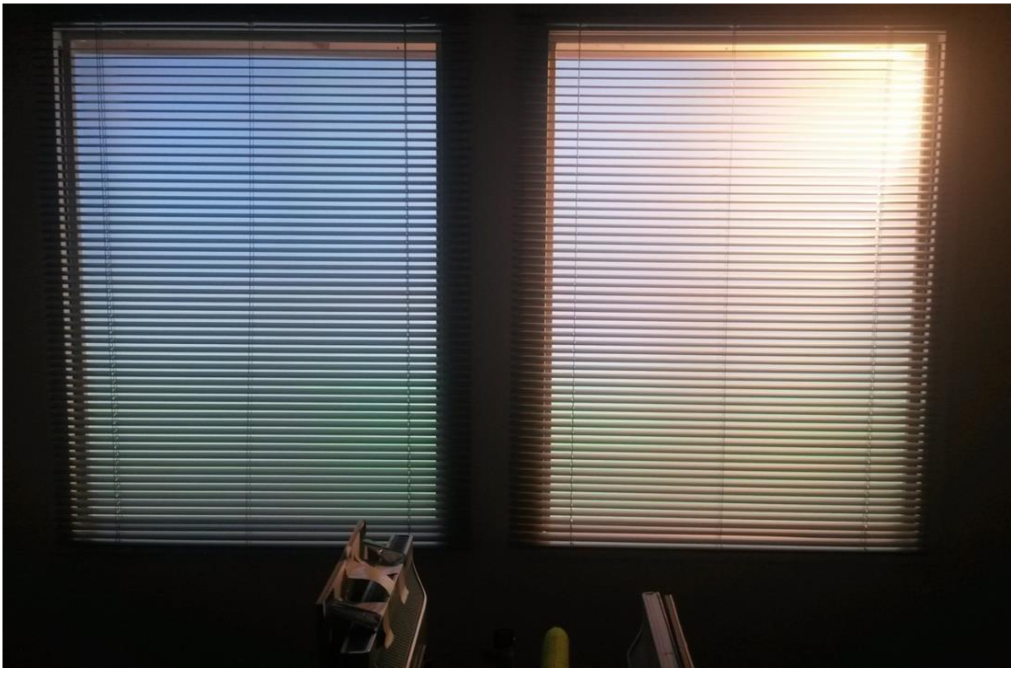


Figure 41 Virtual window in study 1 with blinds lowered and with horizontal slats

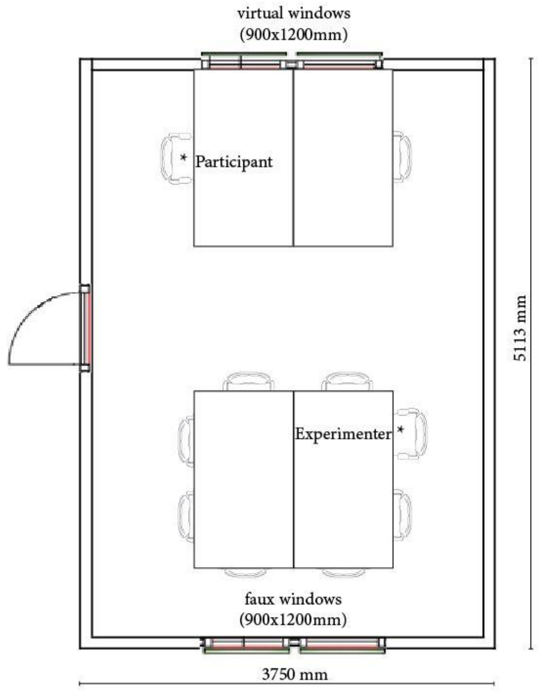


Figure 42 Layout study 1

8.3.3 Procedure and measurements

Participants were asked to install themselves behind the desk and to read and sign a consent form. They were provided with a short explanation sheet about the purpose and set-up of the study and with a sheet which explained the behaviour of the light feedback system. Each of the three conditions was tested for 15 minutes. After the testing of each version, the user was asked to fill in a questionnaire which assessed the dependent variables. After the testing of all three versions, a semi-structured interview was held to gain a deeper understanding about which aspects of the system participants did and did not like. Users were also asked which version they preferred and why. The total experiment duration was around 90 minutes per participant.

Perceived system personality was measured with the short form Big Five personality questionnaire (Boeree, 2004), with four items per personality dimension, rated on a 7-point scale. Perceived control was assessed with a measure developed for evaluating human-computer interaction (Hinds, 1998). User satisfaction was measured with an own developed questionnaire with a 7-point Likert scale consisting of the following four questions: "How satisfied are you with [the overall blinds system | the light feedback system | the automatic blinds behaviour | controlling the blinds system via the tablet]?".

User interaction with the system was logged to evaluate the effect of the tested conditions on user behaviour, in particular the adherence of the user to the suggestions of the system and his corrections of system actions. Adherence was used as a measure to compare users' behaviour on a low and medium level of automation. With a low level of automation, users could only adhere to and not correct the system, as the system did not effectuate any blind adjustment automatically. Adherence (A) was calculated by counting for each condition the times that a user (i) adheres to a system suggestion (a) divided by the total of 4 received suggestions (2 suggestions to raise the blinds, 2 suggestions to lower the blinds), averaged over participants (n), and expressed as a percentage (see Equation 1). The criterion for adherence to a suggestion to raise the blinds was that the blinds were adjusted by the user before the minimum radiation level was reached (level 1), or by the system, with no subsequent blind adjustments (i.e. corrections) from the user until the next sun break through. A similar criterion was used for adherence to suggestions to lower the blinds, but then for radiation levels of 6 or higher.

Users' corrections were defined as actions of users that were a reaction to the system's action and involved a user initiated adjustment of the blinds position (blind angle adjustments were not included as corrections since the automated behaviour only changed the blinds position and not the angle). Correction (C) was calculated by counting for each condition the times a user (i) corrected a system action (c), divided by the total amount of system actions (s), averaged over participants (n), and expressed as a percentage (see Equation 2).

$$A = \frac{\sum_i^n \frac{a_i}{4}}{n} \times 100\%$$

Equation 1 Adherence

$$C = \frac{\sum_i^n \frac{c_{i,n}}{s_{i,n}}}{n} \times 100\%$$

Equation 2 Corrections

8.3.4 Participants

Participants were either students or Philips employees. The students were recruited by distributing flyers at the Eindhoven University of Technology, by word-of-mouth and by social media. They received a gift voucher for their participation. Philips employees were mostly interns and did not receive an incentive because they participated during work time. Participants did not have prior experience with the system we evaluated. In total, 48 participants took part in the experiment (20 females and 28 males; age range 19-51, mean = 26.1, SD = 7.2).

Table 45 Internal consistency (Cronbach's alpha) for scales used in study 1

Scale	Items	Cronbach's α
Extraversion (discarded)	4	.101
Agreeableness (discarded)	4	.554
Conscientiousness (discarded)	4	.369
Neuroticism (discarded)	4	.517
Openness to new experiences (discarded)	4	.214
Extraversion & Openness (talkative, energetic, creative, curious)	4	.823
Agreeableness & Emotional Stability (cooperative, polite, calm, relaxed)	4	.863
Perceived control	2	.813
Satisfaction	4	.784

8.3.5 Questionnaire results

For each scale, Cronbach's alpha was calculated to test the internal consistency of the measure. The results are presented in Table 45. The internal consistency for the five personality dimensions was low. For conscientiousness, no combination of items resulted in a reliable scale, so this scale had to be discarded. For the other four personality scales, some items were discarded to reach acceptable internal consistency. Given the high correlations between Extraversion and Openness to new experiences on the one hand, and Agreeableness and Neuroticism on the other hand (further named Emotional stability, commonly used if the scale is reversed), these scales were combined for further analysis.

8.3.5.1 Perceived system personality

Perceived system personality was expected to be influenced by both level of automation and type of expressiveness. However, no significant main effect of type of expressiveness on perceived system personality was found. The level of automation did have significant main effects on both Extraversion & Openness ($F=9.281$, $p=.004$) and Emotional stability & Agreeableness ($F=7.578$, $p=.008$). Participants perceived the system with a low level of automation as less 'extravert and open' than the medium level of automation (2.7 vs 3.1), but more 'emotionally stable and agreeable' (4.2 vs. 3.6).

8.3.5.2 Perceived control

Perceived control was also expected to be influenced by both level of automation and type of expressiveness. However, no significant main effect of type of expressiveness on perceived control was found. Level of automation did have a significant main effect on perceived level of control ($F=23.859$, $p=.000$). Participants perceived more control with the low level of automation than with the medium level of automation (5.1 vs 4.0). For both the low and medium level of automation, the perceived level of control was significantly higher than with the original system, with a high level of automation (3.3).

8.3.5.3 User satisfaction

All versions of the system with light feedback (C1-C4) scored higher on user satisfaction than the system without light feedback (C0). Table 46 shows the estimated marginal means for each condition and the results of a paired comparison between the original system (C0) and the other conditions. The two systems with low level of automation (C1 and C3) scored highest on user satisfaction and also the medium level of automation with expressiveness version B (C4) scored significantly higher on user satisfaction than the original system (C0).

8.3.6 Usage behaviour

The number of corrections users made was compared for the three conditions in which an automatic blind adjustment was possible (C0, C2, C4). In case of the original blinds system (C0), on average 50.8% (SE=5.7) of the automatic system actions were corrected by the user. For the two versions with light feedback and a medium level automation with expressiveness version A (C2) and version B (C4), respectively 24.8% (SE=8.4) and 31.3% (SE=8.2) of system actions were corrected. The difference between C2 and C0 was found to be significant (p=0.036). The results on users' adherence in study 1 will be presented in Section 8.4.7 and compared with the results in study 2.

8.3.7 Interview results

During the interview, participants expressed their preferences with respect to the three versions they had experienced (see Table 47). Due to the mixed design, conditions C1-C4 were each experienced by 24 participants and C0 was experienced by all 48 participants. The results show that most participants (87.5%) preferred the versions with the light feedback device over the original blinds system. There was no clear difference in preference between the low and medium level of automation. The main motivations for their preferences are listed in Table 47, with in between brackets the number of participants that provided this reason.

All transcribed interviews were analysed to reveal the important themes that participants brought up when asked about their experience with the automated blinds system. These themes are convenience, subtlety, fine-grained control, learning, decision support, personal comfort, and transparency. Next, participants' comments on each of these themes are described in more detail, again with in between brackets the number of participants that mentioned it.

Many users indicated that regulating the blinds in the office is of minor importance as they want to focus on their main tasks and working activities. Operating the blinds should cost as little effort as possible (26) and should not require thoughtful consideration (18). Participants liked the fact they could control the blinds from their chairs via the tablet. *"I find it too much effort to stand up from my chair and walk to the knob"*. Many participants particularly liked the fact that the blinds would raise automatically after a period of high radiation (11). *"I really like that the blinds go up automatically. It was really a happy moment that more daylight entered the room. Otherwise, it could be that you are busy and in a dark room for an hour."*

Table 46 User satisfaction for the tested conditions (A=level of automation, E=type of expressiveness, EMM=estimated marginal means, SE=standard error)

Condition	EMM	SE	Mean difference with C0	p-value
C0(A_{high}, E_{none})	3.488	.150	n/a	n/a
C1(A_{low}, E_{grad})	4.176	.194	-.688	.004
C2(A_{med}, E_{grad})	3.958	.200	-.470	.183
C3(A_{low}, E_{puls})	4.190	.211	-.701	.010
C4(A_{med}, E_{puls})	4.090	.192	-.602	.018

Table 47 Users' preferred conditions including main motivations (A=level of automation, E=type of expressiveness)

Condition	Preferred by	Main motivations for preference
C0(A_{high}, E_{none})	3 out of 24	Don't want to put effort in regulating blinds (2) Want to concentrate on my work.(1)
C1(A_{low}, E_{grad})	10 out of 24	Automatic actions of other versions are conflicting with my preferences (4) Want to be in control. (3) Don't want to be distracted by automatic behaviour (3)
C2(A_{med}, E_{grad})	11 out of 24	Want some control myself (3) Like to be informed (3)
C0(A_{high}, E_{none})	3 out of 24	Don't want to put effort in regulating blinds (2) Want to concentrate on my work (1).
C3(A_{low}, E_{puls})	10 out of 24	Automatic actions of other versions are conflicting with my preferences (5) Want to be in control. (2)
C4(A_{med}, E_{puls})	11 out of 24	Don't want to take care of blinds continuously (7) Want some control myself (2)

As most users consider controlling the blinds of secondary importance in their work environment, they want the systems to be subtle in its behaviour and presence. The blinds system should limit the times it interrupts users from their work (25), the feedback system should not be in the centre of attention (12), and the system should be reserved (7). Especially participants that experienced the expressive version with pulsating red light (version B) commented on this aspect. *"I think the flickering is a bit too much. If all systems would ask that much attention…"*.

Although operating the blinds was considered of limited importance, many participants expressed the desire for more fine-grained control. For some users, the predefined settings with a choice for a few blinds positions and a few angles was not sufficient, and they want to control the blinds more precisely (18) at a position or angle.

Participants mentioned the importance of a system that adapts to individual preferences, and wanted the system to act automatically according to the users preferences (11) and learn from users' behaviour (11). *"I would like to have the system act to my preferences. I don't want to make adjustments the whole time; that is annoying". "The system should actually learn what appropriate behaviour is".* Some participants also mentioned they want a way to communicate their preferences to the system (4).

Many participants liked the light feedback and mention the system should support users in making a decision (23). *"I think the feedback is useful, it feels like you get advice".* However, another group of participants believes that users should be able to regulate the blinds according to their own comfort (22). *"I didn't care about the system's suggestions. I don't care about energy efficiency of the office, it is just about whether I think it is comfortable"*. *"For my comfort, it is not necessary that the system does anything. I experience myself whether it is annoying".*

Finally, several participants commented on the lack of transparency of current automated blind systems. They expressed that the system should give users insights into the outside situation, especially when the blinds are lowered and closed (11). Some also mentioned they want the system to communicate its actions to the user in advance (7) so they can anticipate. *"When it is automatic, I don't know when it is going to move. But when I change them myself then I can take a water or something until the noise is over"*.

8.4 Study 2: effect of type of light feedback on satisfaction and usage

8.4.1 Introduction

The results in study 1 showed no significant effects of the type of expressiveness on perceived system personality and perceived control. This factor was tested between subjects, while level of automation – which had significant effects on perceived system personality and perceived control – was tested within subjects. It could be that the effects of expressiveness were not found due to this study design. Therefore, a second study was designed to test the type of expressiveness within subjects at a fixed level of automation. Furthermore, the measure for perceived system personality was adapted given the low internal consistency in study 1.

8.4.2 Study design

The design of study 2 resembles to a large extent the design of the first study. In this section, we highlight the differences between the study designs. In study 2, the level of automation was held constant at the medium level, as this allowed to investigate the mixed control situation including the number of system actions corrected by the user. Two types of expressiveness were included similar to study 1. However, the behaviour of the arrows was slightly adjusted based on the comments of users in study 1 on the visibility and clarity of the behaviour. Version A in study 1 changed the colour of the arrows from green to red in 10 steps, each displayed for 5 seconds. In study 2, the colour change consisted of only 3 steps, each displayed for 25 seconds. For version B, the difference in pulsing rate between the start and the end of the light behaviour was increased to make the difference more noticeable to users. In three steps, the pulsing rate increased from 0.44 Hz, to 1.33 Hz, to 4 Hz. Furthermore, the light feedback device was now placed under the window instead of above such that it would be easier for users to look at the feedback device. Each participant experienced in a balanced order both expressive versions of the blinds system with a medium level of automation. The conditions of study 2 are represented in Table 48.

Table 48 Overview of conditions study 2 (A=level of automation, E=type of expressiveness)

	Version A (gradual)	**Version B (pulsating)**
Medium automation	C2a(A_{med}, E_{grad}) System suggests and acts; Green-to-red light.	C4a(A_{med}, E_{puls}) System suggests and acts; Pulsating red light.

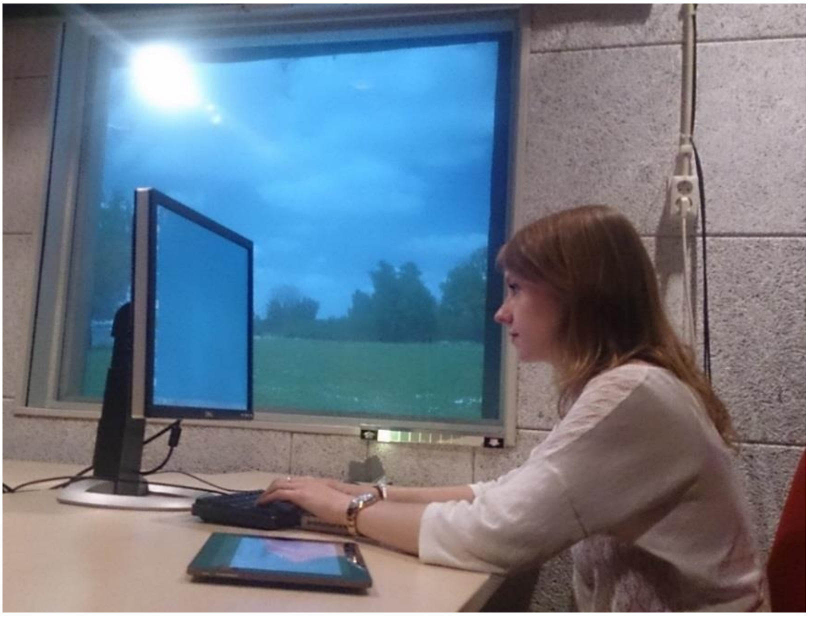


Figure 43 Experimental setting study 2

8.4.3 Materials and setting

The study was conducted in a usability lab at the Eindhoven University of Technology with two spaces connected by a glass window. In the first space, an office setting was created resembling the office setting in study 1, while in the second space a virtual natural view (projection) and virtual sun (LED spot) were positioned close to the window to mimic daylight conditions in the first space (see Figure 43). A light scenario was created comparable to the scenario in study 1. Due to the differences in experimental setting (room size, window size, reflectance of walls, ceilings, floor, virtual view, etc.), the light intensities of the virtual sun were adapted. Again, the threshold for discomfort glare was set based on a few trials with lighting experts subjectively evaluating level of discomfort at various light intensities of the virtual sun. The same tablet was used to manually control the blinds position and angle.

8.4.4 Procedure and measurements

Also the procedure of study 2 was comparable to study 1. However, in study 2, each participant only experienced two versions. Each version was experienced for 17.5 minutes and included two light scenarios. The total duration per participant was around 70 minutes. After each version, a questionnaire was completed and the experiment ended with a short semi-structured interview, this time focusing on the expressive behaviour of the light feedback device.

Table 49 Internal consistency (Cronbach's alpha) for scales used in study 2

Scale	Items	Cronbach's α
Extraversion (talkative, assertive, expressive, confident, dominant)	5	.595
Agreeableness (cooperative, polite, friendly, helpful, agreeable, bossy)	6	.824
Conscientiousness (reliable, persistent, firm, consistent, indecisive)	5	.618
Neuroticism (calm, relaxed, unemotional, patient)	4	.613
Openness to new experiences (creative, curious, intelligent, analytical)	4	.615
Perceived control	2	.662
Satisfaction	2	.602

Similar measures were used as in study 1 but a few measures were adapted. The measure for perceived system personality (Boeree, 2004) was extended with additional personality items selected from (McCrae & Costa, 1987). Each personality dimension was measured with 6 items, resulting in a total of 30 items. For each dimension internal consistency was calculated using Cronbach's alpha. A few items had to be dropped to result in scales with moderate to high internal consistency. For satisfaction, two items were discarded to reach an acceptable internal consistency. Satisfaction with the tablet and the automatic behaviour were left out. The remaining items were satisfaction with the overall blinds system and satisfaction with the light feedback system.

8.4.5 Participants

Participants were recruited at the university and all were students or PhD students. They received a gift voucher for their participation. In total, 24 participants took part in this study (11 females and 13 males; age range 18-30, mean = 23.2, SD = 3.6)

8.4.6 Questionnaire results

8.4.6.1 Perceived system personality

Perceived system personality was expected to be influenced by the type of expressiveness of the blinds system. Table 50 shows the estimated marginal means for the pulsating (C4a) and gradual (C2a) feedback and the results of a paired comparison. From the data, it can be concluded that C4a was perceived as more extravert, less agreeable, more neurotic, and less open to new experiences than C2a.

Table 50 Perceived system personality for the two types of expressiveness (EMM=estimated marginal means, SE=standard error).

	C4a (pulsating)		**C2a (gradual)**		**Paired comparison**	
	EMM	SE	EMM	SE	EMM difference	p
Extraversion	3.885	.182	3.427	.182	.458	.025
Agreeableness	3.521	.174	4.063	.174	-.542	.008
Conscientiousness	4.058	.174	4.169	.174	-.110	.337
Emotional stability	3.292	.174	3.875	.174	-.583	.009
Openness to new experiences	2.979	.131	3.188	.131	-.208	.050

Table 51 Estimated Marginal Means for User satisfaction of C4a and C2a (EMM=estimated marginal means, SE=standard error).

	C4a (pulsating)		**C2a (gradual)**		**Paired comparison**	
	EMM	SE	EMM	SE	EMM difference	p
User satisfaction	3.875	.215	4.125	.215	-.250	.349

Table 52 Percentage of participants adhering to the suggestions of the blinds system

	Type of expressiveness (study 1)		**Type of expressiveness (study 2)**	
	C2 (gradual)	C4 (pulsating)	C2a (gradual)	C4a (pulsating)
Lowering	38.6%	29.6%	77.5%	75.0%
Raising	87.5%	72.7%	87.5%	90.0%

8.4.6.2 Perceived control

The type of expressiveness was also expected to influence the level of control perceived by the participants. The results indeed showed a significant ($p = .038$) difference between the two versions, with C4a resulting in a lower perceived level control (EMM = 4.0) than C2a (EMM = 4.5).

8.4.6.3 User satisfaction

The user satisfaction levels between C4a (EMM = 3.9) and C2a (EMM = 4.1) were not significantly different.

8.4.7 Usage behaviour

For the gradual (C2a) and pulsating (C4) version of expressive feedback, respectively 3.6% (SE=6.0) and 11.6% (SE=6.1) of system actions were corrected. So participants seemed to correct the system with the gradual feedback (green to red light) less than the system with the red pulsating light, although this difference was not significant ($p = 0.179$). The percentages of corrections in study 2 were lower than in study 1 (C2: 24.8% and C4: 31.3%).

Table 52 shows the percentages of participants that adhered to the suggestions of the system in study 1 and study 2. A user action was counted as adherent if it would coincide with a suggestion made by the system. For lowering blinds this was at radiation level 6 to 10, while for raising blinds this was at radiation level 5 to 1. The results show that in general, adherence in study 2 was higher than in study 1, which can be explained by the fact that the light feedback device was placed at a more visible location under the virtual window. In particular for the lowering of the blinds, more users adhered to the system suggestion in the second study than in the first study.

8.5 Discussion and conclusion

Building automation in the work environment might result in occupants losing their sense of control when decisions on environmental aspects are made by technology. In two studies, we investigated the user satisfaction and actual usage of an automated blinds system with an expressive interface installed on a virtual window that was designed to enhance users' perception of control and increase system acceptance. More specifically, the effect of the level automation and the type of system expressiveness on users' satisfaction and usage of the blinds was explored.

The first study showed that the level of automation influences the perceived system personality. Participants perceived the system with a low level of automation as less 'extravert and open' than the system with a medium level of automation, but more 'emotionally stable and agreeable'. Furthermore, as expected, participants perceived more control with the low level of automation than with the medium level of automation. For both low and medium level of automation, the perceived level of control was significantly higher than with the original system, with a high level of automation. The results also showed that the expressive feedback of the light feedback device increased user satisfaction compared to the original system. The feedback also impacted users' blinds usage and reduced the number of system actions that users corrected.

While the results of study 1 did not show any significant effects of the type of expressiveness, the results of the second study showed that the type of expressiveness (when tested within subjects) did affect the perceived system personality. The version with pulsating light feedback was perceived as more extravert, less agreeable, less emotionally stable, and less open to new experiences than the version with gradual light feedback. Furthermore, the pulsating feedback resulted in a lower perceived level of control than the gradual feedback. Study 2 also showed the effect of the type of expressiveness on user behaviour. The pulsating feedback seemed to result in a slightly higher adherence to system suggestions than the gradual feedback. Overall, the adherence in study 2 was higher than in study 1, which can be explained by the fact that the light feedback device was placed at a more visible location. Finally, with the original system in study 1, 50.8% of the system actions was corrected by user. In the second study, with the gradual light feedback, the percentage of corrections was only 3.6%. This indicates that the expressive interface, by providing the light feedback, increased the user acceptance of automatic blind adjustments substantially.

There are a few limitations to the studies presented in this work. First, the studies were conducted in a controlled setting, evaluating only the initial user experience with the blinds system. Daylight and view were simulated. It requires further research to validate the findings in a real office environment under real daylight conditions and over a longer period. For example, during the studies participants experienced a 'breakthrough of the sun' twice within 15 minutes, which is more frequent than on a very cloudy or very sunny day and might have resulted in more negative perception of the more red pulsating feedback. With further validation in a realistic setting, the impact of the expressive interface on blinds usage and hence energy usage can be more accurately predicted. Furthermore, many individual differences were observed between user preferences for type of expressiveness and level of automation. In future work, the role of individual user characteristics in preference for automated blinds systems should be further investigated. It should also be noted that the test subjects of the second study were all in the age group 18-30 years, so not a representative sample of the working population. Further validation with older age groups is needed to generalize the results across the work population. Third, we only evaluated one form of expressive interface for automated blinds, namely a light strip. However, many more expressive interfaces could be designed to achieve a similar effect. It would also be interesting to compare the effectiveness of different implementations of expressive interfaces. For example, the 'personality' of the expressive interface could be adapted to suit the preferences of individual users. Finally, our studies and results are limited to closed office settings and single users. Additional research is needed to investigate user satisfaction with automated blinds and the role of expressive interfaces in open plan offices, as many other factors are expected to play a role, including for example social dynamics.

Despite the limitations, the two studies show many promising results and interesting findings that to our knowledge have not been reported before. This study confirmed previous findings in other domains that people tend to attribute a personality to automated systems for an automated system in the built environment. Not only the level of automation, but also the way a system communicates with the user affects the perceived system personality and how much control users perceive while interacting with the system. The results further show how these factors can impact user's satisfaction with the automated system and the way these systems will be used. The increased adherence to system suggestions and the large reduction in the number of corrections made by the user clearly indicates the potential of expressive interface to increase user's acceptance of automated blinds and thereby realizing the anticipated energy savings. Therefore, expressive interfaces might be instrumental for the future success of building automation systems and ensuring that these will be embraced by occupants and create energy efficient and comfortable work environments.

Part III Summary, discussion, conclusions and outlook

9 SUMMARY, DISCUSSION, CONCLUSIONS AND OUTLOOK

9.1 Introduction

In the introduction chapter of this thesis we described that technological advancements lead to the development of intelligent systems that take decisions and perform actions based on users' context, activities, mood, or anticipated needs and desires. However, as more decisions and actions are automated, there is a risk that people lack the feeling of control and reject the system. An important challenge for designers and engineers is to create intelligent systems that assist people by taking over tasks and decision making, but that still enable users to feel in control.

The main research question we addressed in this thesis is to what extent expressive interfaces can be used to design intelligent systems that have a certain degree of autonomy to perform actions on users' behalf, while still providing users the feeling of being in control. With expressive interface, we referred to the communicative and interactive part of the intelligent system that aims to provide understandable feedback and feedforward information about the internal state, intentions, and actions of the system to the end-user. We hypothesized that expressive interfaces can help users to form a mental model of how the intelligent system works, and facilitate the interaction between the user and the system. We further expected that the expressive interface is able to increase users' feeling of control by affecting three important determinants of control: information, choice and predictability. And consequently, we expected that expressive interfaces can increase users' satisfaction with and acceptance of intelligent systems.

The first part of this thesis focused on the domain of domestic robots and the second part on the domain of automated blinds. In the remainder of this chapter, the key findings per domain are summarized and compared. This chapter ends with the implications of the results for the design of intelligent systems and suggestions for future work.

9.2 Key findings in the domain of domestic robots

Traditionally, robotic technology has been used in controlled industrial settings with limited interaction between humans and the robot. However, advances in technology allow robots to provide services directly to people, at our workplaces and in our homes. In these less controlled environments like offices and homes, with many human beings being present, a fully autonomous robot running a fixed routine and ignoring people is not desirable. Properly designed interaction between humans and robots is needed.

The first question that we addressed in Chapter 2 is whether we could define a user-centred design process to develop expressive interfaces for intelligent systems such as domestic robots. Previous research had shown that robots tend to induce the perception of personality through their behaviour and appearance. We suggested to use the concept of personality as a guiding principle for designing the expressive interface. A well-defined and clearly communicated personality can assist users to form a mental model of the robot and facilitate their interactions with it. We described a process for designing the behaviour of a domestic robot and proposed it as a way to design a personality and appropriate expressions for intelligent systems. The process consists of five main steps, namely:

1. creating a personality profile
2. expressing the personality in behaviour
3. specifying the behaviour in design rules
4. implementing the behaviour
5. evaluating the behaviour with end-users

The process integrates technical, artistic, and user-centred approaches to design a personality for a robotic application. A user-centred approach is proposed to explore what kind of personality people would like the robot to have. Based on this user knowledge, an artistic perspective should be taken to identify expressions and behaviour of the robot with the desired personality. With a more technological perspective the expressions and behaviours are translated into concrete and implementable solutions.

In Chapter 3, the proposed design process was applied in three case studies on the design of robotic vacuum cleaners. Through the case studies, we addressed the questions what kind of personality users expect from a robotic vacuum cleaner and how to express this personality in its behaviour. We also described how the desired personality was implemented in the robotic vacuum cleaners by using motion, lights, and sound. Furthermore, we evaluated how people perceived this expressive interface and whether they recognized the robot's personality as intended by the design.

In the first case study, two distinct personality profiles were created - a more serious and a more playful one – and used to inspire the creation of expressive behaviours for the robot in a variety of situations. Several concepts for expressive behaviours were developed and qualitatively evaluated using virtual representations of the robot behaviour. The results provided insights into how people perceived the expressive behaviours and the different cleaning patterns of the robot, which is valuable information for further design of expressive behaviour for robotic vacuum cleaners and other intelligent systems. Although participants often interpreted the designed expressions in motion, light, and sound in different ways, they could distinguish the serious and playful personality by the type of cleaning pattern. Although the robot with the playful approach was more interesting to watch, the robot with the more serious approach was generally preferred because this pattern was better understood, more trustworthy, and perceived to lead to a better cleaning result.

In the second case study, the Big Five theory of personality was used as a theoretical framework to investigate the desired personality for a robotic vacuum cleaner. Personality traits were used as triggers during interviews with potential end-users to help them express their desires with respect to the personality and behaviour of the robot. In line with the findings of the first case study, the results showed that people desired a serious, service-minded, and systematic cleaning assistant. The desired robot behaviour was captured in twenty-five design rules and twelve usage scenarios were created. These scenarios were textual descriptions of the robot behaviour in various situations. The scenario that was most appreciated by the participants was developed into an 'experience prototype' on a physical robot platform. A pointing device was developed that allowed users to point to a spot on the floor and instruct the robot to clean it. Two versions of this prototype were evaluated with potential end-users: an expressive version that would give light and auditory feedback when receiving commands from the users and a non-expressive version that would execute the command without expressions in light or sound. Although the sample size of this study was very small, some interesting observations were made. The expressive feedback from the robot was subtle and only 3 out of 10 participants indicated that they did notice the difference between the version with and without the expressive feedback. Nevertheless, the expressive feedback seemed to increase the level of perceived control and ease of use, although not statistically significant.

In the third case study, a similar selection of traits from the Big Five theory of personality was used to trigger potential end-users to express their desires with respect to the personality and behaviour of a robotic vacuum cleaner. The results were consistent with the findings of the second case study: participants preferred a dedicated, goal-oriented, and cooperative cleaning assistant. This desired personality profile and matching behaviour were translated into expressions in motion, light and sound. A video prototype was created to evaluate the designed personality and behaviour with potential end-users using a think-out-loud protocol and questionnaires. The results of the evaluation showed that the perceived robot personality matched to a large extent the personality as intended by the designer. Furthermore, the expressions helped in understanding and interpreting the robot behaviour in various situations.

In sum, the three case studies presented in Chapter 3 showed it is possible to design robotic vacuum cleaners that are perceived to have a personality, which comes to expression in its behaviour, more specifically with motion, light, and sounds. Participants were fairly consistent in the type of personality and behaviour they desire from a robotic vacuum cleaner. The results show that they prefer a robot vacuum cleaner that has a somewhat introvert, agreeable, conscientious, and emotionally stable personality. Furthermore, these studies provided first indications that the personality and expressive behaviour were recognized by users and helped them to understand the robot and increased feelings of being in control and ease of use.

While Chapter 3 focused on robotic vacuum cleaners, Chapter 4 described the design and evaluation of a personality for the robotic user interface iCat that helped users to find a TV-programme matching their interests. Two studies were conducted. In the first study, we investigated to what extent it is possible to create convincing and distinct personalities in a robot by an expressive interface using speech, facial expressions, motion, and linguistic style. In the second study, we investigated what personality users prefer for the robotic TV-assistant, what level of objective control they prefer (i.e. how autonomous the robot should behave), and how personality and the level of control relate to each other. The first study demonstrated that it is possible to create convincing personalities of the TV-assistant by applying various social cues. The results of the second study demonstrated an interaction between the effects of personality and level of control on user preferences. Overall, the most preferred combination was an extravert and friendly personality with low level of user control. Participants were more willing to use the extravert and agreeable robot than the introvert and formal one. They also appreciated the recommendations of the extravert and agreeable robot more than those of the introvert and formal one, although both used exactly the same recommendation strategy. Additionally, it was found that the perceived level of control was influenced by the robot’s personality. This suggests that the robot’s personality, as expressed through the expressive interface, can be used as a means to increase the amount of control that users perceive. Possibly, the more expressive, informal robot behaviour is more consistent with a cooperative relation between user and robot and the more formal behaviour induces an impression of high system control.

9.3 Key findings in the domain of automated blinds

In the second part of this thesis, we shifted our focus to the domain of building automation. We described that, as a result of the technological advances and the increasing focus on energy efficient buildings, simple forms of building automation including automatic motorized blinds systems found their ways into office environments. The related work shows the importance of appropriate daylight control for energy saving and user comfort in the working environment, but only limited field studies have been conducted to investigate how occupants experience and use automatic daylight management systems in a real working environment. In Chapter 5, we reported the results of a five-month field study, in which qualitative and quantitative methods were used to investigate how office workers in 40 offices experienced and used automatically controlled exterior venetian blinds with options for manual override and switching off the automatic mode.

In total, 3433 blinds adjustments were recorded, of which 73.6% was initiated by the user and only 26.4% was triggered automatically. Our findings seem to support the statements in the introduction of this thesis that a high user acceptance of automated systems is not easy to achieve; most occupants switched off the automatic mode. Various reasons for not using the automatic mode were identified. First, most office workers highly appreciated daylight in their work environment and enjoyed having a view to the outside world. Second, occupants generally desired to have a sense of control over their working environment and did not accept that a system automatically decides to adjust the blinds on their behalf. This was particularly true if the adjustment was not in line with their current needs (e.g. lowering the blinds when they want to maximize daylight entrance) or if the reason for the automatic adjustment was not clear for the office worker. Contrary to our expectations, users of the manual mode were not more satisfied with the indoor climate or the daylight conditions than users of the automatic mode. Both manual mode and auto mode users with manual override experienced to be in control over the blinds and were reasonably satisfied with the indoor climate. This led to the conclusion that it is not the actual control mode that influences the comfort of office workers, but rather the experienced level of control (i.e. did they experience the level of control to be sufficient for their needs).

Additionally, the results of the field study revealed four different blinds usage profiles that varied in the number of adjustments that were made and in the proportion of manual adjustments. In Chapter 6, we reported a study on the impact of the four different usage patterns on the energy consumption for heating and cooling. The simulation results indicated that the average heating and cooling load for users who used the automatic mode were lower than for people who switched off the automatic mode. In particular, much more energy for cooling was needed in the offices that did not use the automatic mode. Hence, it is problematic from an energy saving perspective that a large majority of occupants switches off the automatic mode of an exterior blinds system. We argued it is worthwhile to investigate ways for improving the acceptance of automated blinds systems; not only for increased comfort of the building occupants, but also for a reduction of the energy consumption in buildings.

One direction we proposed is to make building occupants more aware of the way automated blinds systems work and the impact of the blinds usage on the energy consumption in a building. If the automatic blinds system would communicate to users about its automatic blinds adjustments through an expressive interface, this could increase the acceptance of automatic blind changes.

In Chapter 7, we described the design of an automated blinds system with an expressive interface. A similar design process as presented in Chapter 2 was applied. We addressed the questions what kind of personality people expect from an automated blinds system and how this personality can be expressed and implemented. The results on the desired personality profile indicated that the automated blinds system should be polite, cooperative, efficient, easily discouraged, calm, creative, and curious. In addition, it should be predictable, respond swiftly, be flexible, work in the background, be attentive and have the courage to take decisions. The ideas on how this personality could be expressed in the behaviour of the automated blinds system were clustered into the five categories representing the key characteristics of ambient intelligent systems: embedded, context aware, personalized, adaptive, and anticipatory. An additional cluster of ideas was identified, specifically about the expressivity of the system by giving feedback and feedforward information. Some of these ideas were developed further and implemented as a light feedback device embedded in the blinds system. This ambient light feedback device – the expressive interface - was designed to provide users with information on the actual outside daylight conditions and upcoming or recommended blind changes.

In Chapter 8, we reported two studies in which the expressive interface designed for the automated blinds system was evaluated with users. More specifically, we investigated the effect of the level of automation and the type of system expressiveness on users' satisfaction and usage of the automated blinds system. The first study showed that the level of automation influenced the perceived system personality. Participants perceived the system with a low level of automation as less 'extravert and open' than the system with a medium level of automation, but more 'emotionally stable and agreeable'. Furthermore, as expected, participants perceived more control with the low level of automation than with the medium level of automation. For both low and medium level of automation, the perceived level of control was significantly higher than with the original system with a high level of automation. The results also showed that the expressive interface increased user satisfaction compared to the original system and impacted blinds usage by reducing the number of system actions that were corrected by users. While the results of the first study did not show any significant effects of the type of expressiveness, the results of the second study showed that the type of expressiveness did affect the perceived system personality. A version with red pulsating light feedback was perceived as more extravert, less agreeable, less emotionally stable, and less open to new experiences than a version with gradually colour changing light feedback. Furthermore, the pulsating feedback resulted in a lower perceived level control than the gradual feedback. The second study further showed the effect of the type of expressiveness on user behaviour. The pulsating feedback resulted in a slightly higher adherence to system suggestions than the gradual feedback. Finally, with the original system in the first study, 50.8% of the system actions was corrected by the users. In the second study, with the gradual light feedback, the percentage of corrections was only 3.6%. This indicates that the expressive interface, by providing the light feedback, increased the user acceptance of automatic blind adjustments considerably.

To conclude, the studies in Chapter 8 confirmed that people tend to attribute a personality to automated systems, also in the built environment. Not only the level of automation, but also the way a system communicated with the user affected the perceived system personality and how much control users perceived while interacting with the system. The results further showed how these factors affected user's satisfaction with the automated system and the way these systems were used. The increased adherence to system suggestions and the large reduction in the number of corrections made by the user clearly indicated the potential of the expressive interface to increase user's acceptance of automated blinds and thereby realizing the expected energy saving. Therefore, expressive interfaces might be instrumental for the future success of building automation systems and ensure that these systems will be embraced by occupants and create energy efficient and comfortable work environments.

9.4 Discussion and comparison of the findings

In this section, we compare and discuss the key findings of the studies in the two domains. First, we discuss using personality as a guiding principle to design intelligent system behaviour. Then, we discuss the commonalities and differences we found in the desired personality for the various intelligent systems. Third, we discuss how the personality was reflected in the expressive interface in the various embodiments of the intelligent system. Finally, we discuss the effects of the expressive interfaces on the perceived level of control, the perceived system personality, and users' acceptance of the intelligent system.

9.4.1 Personality as guiding principle

In both domains, the notion of personality proved to be useful as a guiding principle when designing the interface and interactions with intelligent systems. Personality is a psychological construct that is widely known and familiar to people. In most of our languages, we have a very rich set of adjectives to describe human personality in detail and with nuance. We experienced the Big Five personality model to be a useful tool to communicate about the desired interactions with intelligent systems. It helped end-users, application researchers, designers, marketeers, and engineers to think about and express the desired characteristics of intelligent systems beyond the technical features or user interfaces that are visible at the surface. It helps people to formulate the essence of the intelligent system: the combination of characteristics or qualities that form the distinctive character of the system.

9.4.2 Desired personality for intelligent systems

We found a high consistency between the desired personality profiles for the various robotic vacuum cleaners. People expected a serious, service-minded, systematic, dedicated, goal-oriented, and cooperative cleaning assistant in all three case studies. The results on the desired personality profile for the automated blinds system indicated that it should be polite, cooperative, efficient, and attentive. For the robotic TV-assistant however, people preferred a more friendly and extraverted personality over a more formal and introvert one. Figure 44 provides a visual summary and interpretation of the results on the desired personality profile for the three type of intelligent systems that were investigated in this thesis: the robotic vacuum cleaners, the robotic TV-assistant iCat, and the automated blinds system. On the dimensions of agreeableness and emotional stability the results among the applications are consistent: people desire an agreeable and emotionally stable intelligent system. For the other three dimensions, extraversion, conscientiousness, and openness, the results vary per application. The figure reflects the author's interpretation of the results. It should be noted that a clean comparison of the results is not possible due to the many methodological and application-specific differences in the various case studies. In addition, it should be noted that the personality profile of the TV-assistant application was only specified for three of the five personality dimensions. Nevertheless, it is a very interesting result of our empirical studies in various domains that the desired system personality seems to depend on the application and context of use.

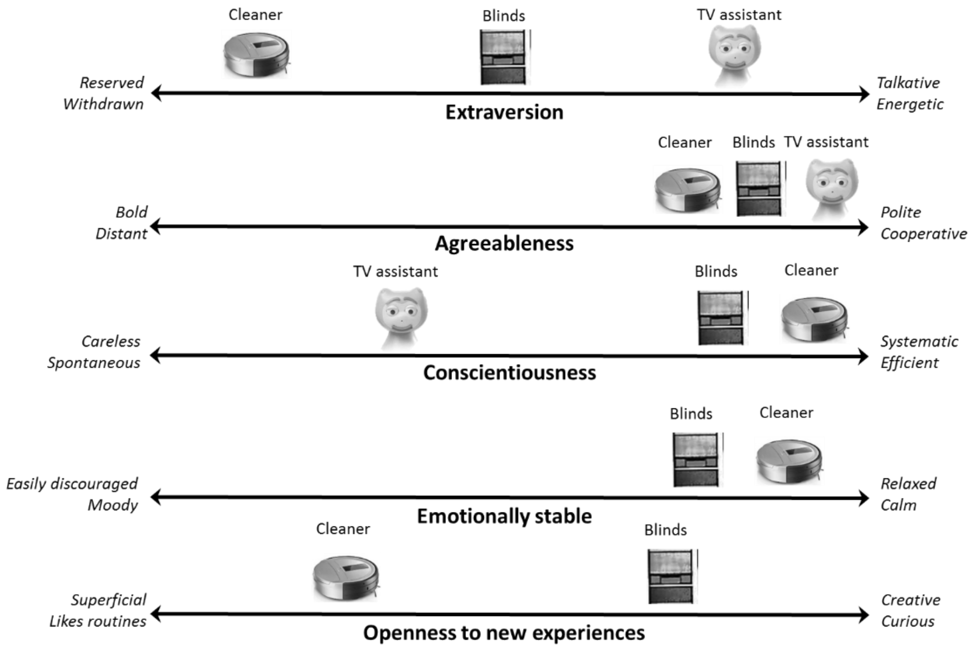


Figure 44 Visual impression of the desired personality profile for the three intelligent systems investigated in this thesis: robotic vacuum cleaners, iCat as TV-assistant, and automated blinds.

9.4.3 System's personality reflected in the expressive interface

We explored various ways to express personality in the behaviour of the intelligent system and evaluated whether people could recognize personalities as intended by the design. In the case of the robotic TV-assistant, we could create a relatively direct mapping of personality expressions that are known from human-human interactions to the expressive capabilities of the iCat. Social cues in speech and intonation, facial expressions, body movements, and linguistic style were used to create convincing and distinct personalities. To a large extent, users recognized the personalities as intended by the designer. In the case of the robotic vacuum cleaners, a direct mapping of expressions in human-human interactions to the human-robot interaction was not possible due to the limited expressive capabilities of the robotic vacuum cleaners. While iCat was designed to mimic human-like expression in its face, via speech and body movements, the robotic vacuum cleaners were more abstract physical objects and had less possibilities to express themselves. The vacuum cleaners used motion, light, and sound (but no speech) to express their personality. Despite the fact that the expressions of the robotic vacuum cleaners were less rich and less human-like than those of the iCat, the results did show that people could recognize to some extent the different personalities as intended by the designer. In the case of the automated blinds system, we only used light to express different personalities. Although the expressive capabilities of the ambient light feedback device were more limited than those of the iCat and the robotic vacuum cleaners, users could still recognize the differences in personality as intended by the designer. A version with red pulsating light feedback was perceived as more extravert, less agreeable, less emotionally stable, and less open to new experiences than a version with gradually colour changing light feedback.

Although the iCat, through its anthropomorphic appearance and rich set of human-like expressive capabilities, could convey more convincing and rich personalities than the automated blinds, we showed that even a simple dynamic light pattern can induce people to attribute a personality to an intelligent system. This is in line with earlier work on animacy and personality attribution (Heider & Simmel, 1944; Reeves & Nass, 1996; Tremoulet & Feldman, 2000).

9.4.4 Effect of expressive interfaces on perceived control and automation acceptance

We hypothesized that expressive interfaces - by communicating information about the internal state, intentions, and actions of the intelligent system towards the user - could help the user in forming a mental model of how the intelligent system works, and facilitate the user-system interaction. We further expected that the expressive interface would be able to increase users' feelings of control and consequently increase users' satisfaction and acceptance of intelligent systems.

The three case studies on robotic vacuum cleaners provided deeper insights into users' perception of the expressive interface. For Eagle, the designed expressions in motion, light, and sound were often interpreted differently by the participants. However, the qualitative results showed that some expressions were interpreted as intended by the designer and helped users form a mental model of how the intelligent system worked. The user test with Falcon revealed that the subtle expressive feedback seemed to increase perceived level of control and ease of use of the cleaning robot, although not statistically significantly. Finally, the user evaluation of Dusty showed that the expressions in motion, light, and sounds could help users to understand and interpret the robot behaviour in various situations. All in all, the robotic vacuum cleaner case studies showed qualitative support for the potential of expressive interfaces to communicate the system's internal state, intentions, and actions towards the user, using personality as a guiding principle. In addition, the results provided some first indications that the expressive interface could also increase user's perception of control. However, the studies were too qualitative, explorative, and small scale to provide strong evidence of the effect of expressive interfaces on perceived control and system acceptance.

The study with the robotic TV-assistant iCat demonstrated that participants were more willing to use the extravert and agreeable robot than the more introvert and formal one. Participants also appreciated the recommendations of the extravert and agreeable robot more than those of the introvert and formal one, whereas both used exactly the same recommendation strategy. Additionally, it was found that perceived level of control was influenced by the robot's personality. These results confirm the hypothesis that a robot's personality, as expressed through the expressive interface, can be used as a means to increase the amount of control that users perceive and system acceptance.

The results of the study with the automated blinds system showed that the expressive interface increased user satisfaction compared to the original system. The expressive interface also impacted blinds usage and reduced the number of system actions that users corrected. While the results of the first study with the automated blinds did not show any significant effect of the type of expressiveness, the results of the second study showed that the type of expressiveness did affect the perceived system personality and the perceived level of control, confirming our expectations.

9.5 Recommendations for future research

In this thesis, we presented a collection of studies on user control in ambient intelligent systems. These studies resulted in many interesting findings - summarized in the previous sections - and thereby contributed to the existing research on human-computer interaction and ambient intelligent systems, and more specifically to the fields of human-robot interaction and human interaction with the built environment.

In sum, the main contributions are:

- A proposal for a user-centred design process to develop expressive interfaces for intelligent systems using the concept of personality as a guiding principle (Chapter 2)
- Application of the proposed design process to practical case studies in two different domains (Chapters 3, 7)
- Insights into users' expectations and desires in relation to the personality and behaviour for various intelligent system applications (Chapters 3, 4, 7, 8)
- Guidelines for designing personalities and behaviour through expressive interfaces using motion, light, sound, and social cues. (Chapters 3, 4, 7 ,8)
- Confirmation that intelligent systems that do not communicate and interact with users in an appropriate way have a low acceptance (Chapter 4, 5, 8)
- Evidence that the level of automation (i.e. the objective level of control

available to the user) influences the perceived system personality and the perceived level of control (Chapters 4, 8)

- Evidence that the expressive interface (i.e. system personality) influences the perceived system personality, the perceived level of control, and user satisfaction with the system (Chapters 4, 8)

Although many contributions were made, there are several limitations to the work that need to be understood to interpret the findings in a correct way. Furthermore, there are still many open questions related to user control in ambient intelligent systems. Based on the limitations of our work, we provide some recommendations for further research that could help to design future intelligent systems that are loved by its users.

Our research focused on two domains (domestic robots and automated blinds) with specific characteristics as described in section 1.5. Therefore, the results cannot be generalized to all ambient intelligent systems. Additional research in other application domains is advisable to investigate whether our findings can be reproduced. We expect that the preference for the type of system personality, the particular design of the expressive interfaces, and the effectiveness of the expressive interface to increase perceptions of control and user satisfaction are application specific. However, we believe that the general desire of people to feel in control while interacting with the intelligent system will be strongly present in all domains. Systems that cannot meet users' expectations on the level of control will not be appreciated or even rejected.

Another limitation of this work is that the studies were conducted in applied settings, either in naturalistic laboratory settings (e.g. ExperienceLab) or in a field study. Conducting research in these applied settings inevitably introduced a myriad of external factors that were not under the control of the investigators and might have impacted the results. Although studying the topic in an applied setting increases the ecological validity of the research, it is more difficult to reach a high internal and external validity of the results. In most of the studies it was not possible to separate the effects of the functionality of the intelligent system, its physical appearance, and the behavioural aspects of the system. For example, when investigating to what extent a designed personality could be recognized by users, the judgements of people were based on the holistic experience after their interaction with the intelligent system, and were not based on the designed expressions in isolation. Further research could perform studies in more controlled laboratory settings to investigate the underlying mechanisms that create feelings of control in the interaction with intelligent systems and to systematically examine the effects of various parameters in isolation.

Starting from Norman's idea that a personality could help people to form a mental model of the system, we applied the Big Five theory of human personality to design the personality of intelligent systems. A selection of human personality traits was made and proved to be useful for discussing and communicating about the desired personality of the system. However, another selection of traits could have been used, as for example done by Mugge and colleagues for assessing a product's personality from its appearance (Mugge et al., 2009). The Big Five personality model uses a rich set of traits to describe the human personality with a high level of detail and nuance. It might be that for intelligent systems a simplified personality model would be more appropriate. Moreover, other psychological constructs might be useful when designing desirable interactions with intelligent systems, for example emotions or social intelligence (De Ruyter, 2010; Ortony, Clore, & Collins, 1990). Further research could explore and compare several of these psychological constructs that are used in designing intelligent systems.

Another limitation of our work is that most of the studies, except for the field study in Chapter 5, investigated the experience of users only after initial use of the intelligent system. Long-term evaluations are needed to investigate whether the effects that were found in short-term interactions are valid for long-term interactions with intelligent systems. Moreover, all studies were conducted in The Netherlands. Although people with different nationalities and cultural backgrounds were involved as participants of the studies, the results are strongly biased towards the North-west European situation. There might be cultural and regional differences with respect to the perception of intelligent systems and the desire for control, as for example found in a cross-cultural study with robots (Evers, Maldonado, Brodecki, & Hinds, 2008). Similarly, for the automated blinds systems we expect different results in other regions. For example, the North-west European desire to maximize daylight entrance in the buildings as found in our studies might not exist in a region with a different climate (e.g. Dubai). The cultural and regional differences would be an interesting topic to explore further.

Finally, in our studies we investigated intelligent systems with different levels of control and different types of personality. We found individual differences in the desired level of control, the desired personality, and the type of behaviour and expressions. It would be interesting to conduct further research on these individual differences, so future systems could be adapted and personalized to the needs of the individual user. Research on human interpersonal relationships show that in most situations similar personalities attract, although some research indicates that complementary or opposite personalities attract (Byrne, 1971; Dryer & Horowitz, 1997). This suggests that users should be able to choose the personality of the intelligent system. Similarly, the level of automation could be adjustable by users to meet their desired level of control in the interaction with the intelligent system, as also suggested by (Parasuraman et al., 2000).

9.6 Outlook for Ambient Intelligent Systems

We started this thesis stating that humans have an innate need to experience control and be effective in interactions with their environment. The past decades we have witnessed how technological developments have introduced increasingly intelligent systems into our daily lives. Some systems we have embraced and others we have rejected due to reduced feelings of control. And now, we are entering a new era of Ambient Intelligence where we will be surrounded by intelligent systems including health advisors (Your.MD, 2016), beer serving drones (Bluejay, 2016), self-driving cars (Google, 2016), and smart lighting systems (Philips Hue, 2016) that are all connected through the Internet.

The Internet of Things (IoT) developments are accelerating the creation of networks of these intelligent systems and objects embedded with electronics, software, sensors, and network connectivity that enable real-time and large scale data collection, exchange, and analysis. Big quantities of data are collected and processed using cloud computing platforms and shared among the 'things'. The 'things' are always-on (Aarts, 2013), always connected, always processing and analysing the data, and always deciding how to act upon it. The amount of data and total processing power that becomes available when billions of devices are connected is virtually infinite. These technical developments will lead to new research questions related to the topics that were investigated in this thesis.

In line with the work of Reeves and Nass (Reeves & Nass, 1996), we used the principle of animacy (the attribution of lifelike features to technology) to motivate the design of a system personality that will help users to form a mental model. But if people interact with the IoT consisting of billions of connected devices, will it be clear with whom they are interacting and where the boundaries of the system are? Will they still regard the system as a single entity or agent they communicate with? Will they understand who is actually making decisions or providing recommendations? How will this affect their feelings of control? The acceptance of these complex, distributed, and data-centric systems will require people not only to feel in control while interacting with them, but – since the systems are always-on – also require a deeper level of trust that the technology will pursue actions that are in the best interest of the user. Basic conditions including security and privacy of users need to be fulfilled, but perhaps more is need to make people really embrace intelligent systems. The key success factor of future intelligent systems might be their ability to address the three fundamental human needs as described in the introduction chapter: autonomy, competence, and relatedness. Although this thesis provided some answers and directions, it raised many new questions that need to be addressed in future research.

It remains a challenge to design intelligent systems in such a way that they support our everyday activities and complement human beings rather than replacing them. Norman describes two different directions for intelligent systems in the future: one toward intelligent autonomy and the other toward intelligent augmentation (Norman, 2007). Intelligent autonomy refers to the systems that attempt to infer the intentions of people, while intelligent augmentation is about providing useful tools and letting people decide when and where to use them. In our view, both type of systems will likely co-exist in the future. For some application areas and some users, intelligent autonomy will do the job, while in many situations intelligent augmentation will be the preferred option. For the successful adoption of these intelligent technologies, it becomes even more important than before that the basic human needs of competence, autonomy, and relatedness are satisfied. This thesis showed the potential of the expressive interface as an instrument that can help users understand what is going on inside the system, to feel in control and intervene when needed, and to relate to the system. Finally, we expect that we will need systems with various levels of automation and different types of system personality - as explored in this thesis – to meet the needs of different individuals, at different times, in different places, and in different application areas. Time will tell how successful humankind will be in developing intelligent systems that are kind to humans.

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CURRICULUM VITAE

Bernt Meerbeek was born on 28-02-1981 in Tholen. After finishing his VWO in 1999 at Roncalli S.G. in Bergen op Zoom, he studied Information Systems & Management at Tilburg University. In 2003, he graduated on the topic of intelligent agents in communication systems. After receiving his Master's degree in 2003, he joined the User-System Interaction program at the Stan Ackermans Institute at the Eindhoven University of Technology. He graduated in 2005 and received his Professional Doctorate in Engineering (PDEng) on the topic of user-system interaction. Since 2005, Bernt is employed as scientist at Philips Research focusing on the user experience of ambient intelligent systems. In 2010 he started a PhD project at the Eindhoven University of Technology of which the results are presented in this dissertation.

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After more than 70.000 words describing the studies on user control in Ambient Intelligent systems that I conducted the past decade working at Philips Research, it is time for the most important words of this thesis.

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Bernt Meerbeek