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The societal impact of smart appliances for connecting homes and grids

Usage and user experience of Dutch residents

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The societal impact of smart appliances for connecting homes and grids

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Summary

Implementing sustainable and energy-efficient solutions
In the European project Interconnect ([Interconnect Project - Homepage](#)),
50 European entities have developed and implemented advanced solutions
for connecting and converging digital homes and buildings within the electricity
sector. In 2023 at a large-scale Dutch real life demonstrator at Strijp S in Eindhoven ([NEXT, Strijp S Eindhoven - Wonen bij bouwinvest](#)), four smart devices have been implented in 99
residential appartments each: a smart washing machine, dryer, dishwasher (white goods)
and an automated air ventilation system. These appliances have been designed to stimulate
consumers to use energy when there is a large amount of sustainable energy (wind, solar),
and less energy when there is a limited supply of energy. One key feature integrated into
these connected devices is a function called 'delayed start time,' which autonomously
selects the most sustainable moment to activate the appliance within a designated time
frame. This feature can be operated through either an app or the device itself. The
underlying principle is straightforward: the longer the delay in starting the appliance, the
greater the potential for more sustainable energy consumption. Furthermore, for consumers
with dynamic energy contracts, delayed starts correspond to cost savings, as they align with
periods of lower energy tariffs. As a result, these appliances facilitate the integration of
renewable energy sources into the existing grid infrastructure.

The goal of the current study is to monitor the usage and user experience regarding the four
types of smart devices by means of three questionnaires over a period of nine months.
Additionally, seven interviews were held to gain in-depth insights into the usage and user
experienc of the smart appliances. More specifically, the following five pre-defined key
performance indicators (KPIs) have been measured:
1. Rise in energy awareness due to the InterConnect project
2. Usage of the four smart appliances
3. Ease of use of the four smart appliances
4. Satisfaction with the four smart appliances
5. Perceived value of the four smart appliances.

Additionally, we have gained qualitative insights on complains and suggestions for further
improvement.

Conclusions
Overall, this study demonstrates the successful implementation of the four smart appliances
in the Next building in Eindhoven. However, usage of the delayed start feature is still limited
to a small number of individuals who are aware of its existence and has not significantly
increased over time. Nonetheless, participants have shown increased energy awareness,
and their satisfaction and ease of use with the appliances have significantly improved. The
following six conclusions can be drawn from these findings.

*Energy awareness increased significantly, while knowledge about energy-saving measures
remained high*
Energy awareness showed a notable increase, with participants reporting a 36% rise in their
perception of energy consumption sustainability following their engagement in the
InterConnect project. Despite this, participants demonstrated consistently high knowledge

levels of around 80%, regarding energy-saving measures in their homes. During interviews, participants offered mixed feedback on the project's direct impact on energy awareness, with three participants acknowledging a positive influence on both their understanding of energy consumption and related behaviors. Three participants cited factors such as pre-existing energy-conscious habits, limited familiarity with the InterConnect app, or technical challenges hindering its functionality as reasons for their unchanged awareness levels.

Despite high awareness of the smart features (especially for the white goods), usage did not increase over time
Participants were highly aware of the smart features, especially regarding the white goods, including the washing machine (93%), dishwasher (81%), and tumble dryer (77%). Awareness of the automated air ventilation's smart features was lower (44%). Despite this awareness, usage rates among participants who were aware of these features did not increases over time. On average, the smart features of the washing machine, tumble dryer, dishwasher, and automated air ventilation were utilized by 66%, 64%, 69%, and 73% of those participants, respectively. Interviews with participants revealed diverse efforts to reduce energy consumption, ranging from proactive engagement to encountering challenges and occasional disengagement. Nevertheless, a majority of participants expressed a strong willingness to embrace additional measures for energy conservation.

Ease of use of the white goods significantly increased
The ease of use for all smart appliances notably increased 35% from 41% in the initial measurement to 76% in the final measurement. Specifically, the washing machine (42%), dishwasher (35%), and automated air ventilation (35%) demonstrated significant improvements in ease of use from the first to the last measurement. While there was no significant increase in ease of use for the tumble dryer over time (26%), an upward trend is evident.

Likelihood of recommendation for each smart appliance and satisfaction with the white goods significantly increased
Satisfaction with the smart appliances, as evaluated through Net Promoter Scores (NPS)[1] for each device, demonstrated substantial enhancements over time, increasing by 39 points on a scale from -100 to 100. Direct questions about satisfaction with each smart device revealed that especially the satisfaction with white goods, including the washing machine, dishwasher and tumble dryer, increased significantly by 22%, 22% and 19%, respectively from the initial measurement to the subsequent one. Satisfaction about the automated air ventilation remained relatively unchanged. Further insights from interviews revealed divergent satisfaction levels among participants, partially influenced by varying degrees of engagement with the InterConnect system.

Perceived value of the smart devices remained high
The perceived value of the four smart appliances, measured by asking participants to reflect on the value of each smart appliance (often associated with quality, price and features of a product), remained consistently high at around 85%. While the washing machine was valued the most with 98%, the automated air ventilation was valued least with 67%. During

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[1] The NPS is a widely used metric in customer experience management that indicates the likelihood of customers to recommend a company's product or service to others. It is calculated based on responses to a single question: "On a scale from 0 to 10, how likely is it that you would recommend the following devices and/or services, which are present in your household, to your friends, family or colleagues to a friend or colleague?" Respondents are categorized into three groups: promoters (score 9-10), passives (score 7-8), and detractors (score 0-6). The NPS is then calculated by subtracting the percentage of detractors from the percentage of promoters.

the interviews, participants provided varied responses regarding the perceived decrease in energy consumption since the start of the InterConnect project. Some reported stable costs, while others expressed uncertainty due to a lack of comparative data.

Participants revealed limited knowledge about the functionality of the smart feature and complained about too many emails and the high amount of apps
Concerns were raised regarding the absence or difficulty of using the physical buttons on the smart devices to control the smart feature, indicating a lack of knowledge among the participants. Additionally, participants complained about too many emails and about the high number of apps required for system management. Although these observations were based on a limited number of participants, they offer valuable insights into the challenges experienced by users.

Recommendations
Based on the results of both the three questionnaires and the interviews, we make the following recommendations.

Provide user training and support
In order to close existing knowledge gaps on using the smart feature as well as via the physical buttons, as indicated by some interviewees, we recommend to provide comprehensive training and support materials to ensure users can fully utilize smart feature effectively. By offering for example interactive workshops, online tutorials, and establishing dedicated support channels, such as help desks or online forums, users can receive the assistance they need to optimize their use of the smart appliances.

Provide information about impact, difference in cost and percentage of green energy, for example via a display in the entrance hall of the building.
As indicated by the interviewees, participants want more information on the environmental impact of the InterConnect project and energy savings achieved through participants' efforts, for both their own apartment as well as the whole apartment complex. Participants are also curious about the cost differences between using InterConnect and participants' preferred timing for energy consumption. Finally, participants are curious about the percentage of green energy consumed versus grey energy. Consider implementing a display screen in communal areas (incl. extra protection against vandalism) to showcase real-time energy usage data and savings. This information and transparency can empower users to make informed decisions about their energy usage.

Streamline communication
Reduce information overload by streamlining communication channels and ensuring that information sent via email is concise, relevant, and actionable. Consider consolidating information into fewer emails or providing customizable preferences for receiving updates.

Investigate possible issues with the automated air ventilation
Compared to the other devices, the automated air ventilation has a low NPS (-17), a lower satisfaction score (66%) and perceived value score (67%). We therefore recommend to investigate into the specific issues or concerns related to the automated air ventilation system. A first indicator of possible factors contributing to the lower satisfaction and perceived value scores is the low awareness of the smart features of this device (44%) compared to the other devices. Other factors include technical issues, usability challenges, or inadequate performance compared to user expectations. By gaining more insights about the automated air ventilation, enhancements can be made to improve the user satisfaction and perceived value of this device.

Technical improvements: integration of other devices into InterConnect
Explore opportunities of introducing a power outlet feature within the InterConnect system, enabling users to manually add and control additional devices. This flexibility enhances user autonomy and control over energy usage. Specifically, participants are interested in the integration of home batteries and electric cars.

Contents

1 Introduction

1.1 Implementing sustainable and energy-efficient solutions

7As part of the European project Interconnect ([Interconnect Project - Homepage](#)), 50 European entities have developed and implemented advanced solutions for connecting and converging digital homes and buildings within the electricity sector.

Within this project, four types of smart appliances have been installed in the Dutch large-scale pilot: a smart washing machine, dryer, dishwasher (white goods) and an automated air ventilation system. These appliances have been designed to stimulate consumers to use energy when there is a large amount of sustainable energy (wind, solar), and less energy when there is a limited supply of energy. One key feature integrated into these appliances is the 'delayed start time,' which autonomously selects the most sustainable moment to activate the appliance within a designated time frame. This feature can be operated through either an app or the device itself. The underlying principle is straightforward: the longer the delay in starting the appliance, the more sustainable the energy consumption becomes. Furthermore, for consumers with dynamic energy contracts, delayed starts correspond to cost savings, as they align with periods of lower energy tariffs. As a result, these appliances facilitate the integration of renewable energy sources into the existing grid infrastructure.

In January 2023, the four smart appliances have been implemented in 99 apartments of the new residential tower building named Next, a large-scale demonstrator at Strijp S in Eindhoven, The Netherlands ([NEXT, Strijp S Eindhoven - Wonen bij bouwinvest](#)). In order to monitor the usage and user experience regarding the four smart appliances, Dutch residents have been asked to fill in three questionnaires over a period of nine months. Additionally, seven interviews were held to gain in-depth insights into the usage and user experience of the four smart appliances.

1.2 Scope of the study

In the current study, we focus on the results regarding the following pre-defined key performance indicators (KPIs):
1. Rise in energy awareness due to the InterConnect project
2. Usage of the four smart appliances
3. Ease of use of the four smart appliances
4. Satisfaction with the four smart appliances
5. Perceived value of the four smart appliances.

These KPIs were measured over a period of nine months by means of three questionnaires. In addition to this quantitative monitor, seven interviews were held 6 months after the first measurement to gain an in-depth understanding of these KPIs.

The participants in this study are residents that rent an apartment in the new building named Next at Strijp S in Eindhoven and are willing to participate in this study.

1.3 Method

1.3.1 Quantitative research

To identify the rise in energy awareness due to the four smart appliances, the satisfaction and effort with them, the user adoption, usage, and perceived value of them, three questionnaires were conducted at three points in time over a period of nine months, consisting of approximately 42 questions each. The first questionnaire (0-measurement) was conducted in May and June of 2023, before the (re-)introduction of the smart features for the four appliances, which was delayed due to technical issues. The second questionnaire (1-measurement) took place in November 2023, followed by the third questionnaire (2-measurement) in February 2024, both after the (re-)introduction of the smart features for the four appliances in July 2024. Please see Appendix A for an overview of the questions asked in the three questionnaires.

Quantitative analyses were performed by using the statistical software R Studio[2]. Across the three measurements, a total of 93 renters residing in apartments within the Next building participated in this study. Important to mention is that, due to the availability of the participants and limited resources within the project in terms of incentives, the participants are not the same individuals across the three measurements. However, they are all living in the 99 apartments of Next, in which the four smart appliances have been installed, meaning that they are in the same situation. With an average of 67%, the majority of participants are male, predominantly falling within the age range of 26 to 35 years (M=56%). Roughly half of the participants holds a Master's degree (M=51%) and a significant portion occupies positions as employee (M=45%) or managers/ highly skilled professionals (M=41%). For a detailed overview of the socio-demographic background of the sample, please see Table 1.1.

Table 1.1: Socio-demographic background of the questionnaire sample, including age group, gender, education, and work.

		0-measurement (n=32)	1-measurement (n=32)	2-measurement (n=29)
Gender	Female	25%	31%	38%
	Male	75%	69%	62%
Age group	< 26 years	19%	19%	21%
	26 to 35 years	47%	56%	66%
	36 to 45 years	25%	19%	10%
	46 to 55 years	3%	3%	3%
	56 to 65 years	6%	3%	0%
	> 65 years	0%	0%	21%

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[2] RStudio Team (2020). *RStudio: Integrated Development for R*. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

		0-measurement (n=32)	1-measurement (n=32)	2-measurement (n=29)
Education	No education	0%	0%	0%
	Elementary education/ primary school	0%	0%	0%
	Secondary education/ high school	3%	0%	3%
	College	6%	13%	14%
	Trade/ technical/ vocational training	6%	6%	10%
	Bachelor's degree	28%	19%	21%
	Master's degree	50%	56%	48%
	Professional degree	3%	0%	0%
	Doctorate degree	3%	6%	3%
Work	Manager or highly skilled professional	47%	38%	38%
	Intermediate profession	9%	9%	0%
	Employee	38%	44%	52%
	Self-employed person	3%	6%	7%
	Retired	0%	0%	0%
	Unemployed	0%	0%	0%
	Other	3%	3%	3%

It is important to mention that, due to participant availability and limited project resources for incentives, the individuals participating in the current study are not the same across the three measurements. Although they all reside in the 99 apartments of Next where the four smart appliances have been installed and therefore share the same context, this is a limitation of the current study and should be taken into account when interpreting the results. Additionally, the sample may not be representative of the Next building. While socio-demographic data for all residents is unavailable, participants likely do not represent the entire group of residents, having volunteered randomly based on convenience and willingness to participate. Therefore, while interpreting the results, it should be taken into account that the results may not be generalized to all Next residents.

While the questionnaires were made available online and distributed among participants via email, the majority of responses was collected through in-home visits. This approach was adopted in response to a low response rate observed during the 0-measurement, despite multiple reminder emails sent through the property manager. Acknowledging the lack of participation, the lead researcher of this study, in collaboration with the innovation lead at VolkerWessels iCity, conducted personal door-to-door visits to residents of the Next building. This targeted recruitment strategy was executed six times in total, with two rounds conducted during each measurement phase.

1.3.2 Qualitative research

In addition to the quantitative research, seven interviews[3] were conducted six months after the 0-measurement, spanning from November to December 2023, with each interview lasting approximately 30 minutes. These interviews were conducted online via Microsoft Teams. Two out of the seven participants identified themselves as women and five as men, 5 out of 7 participants were 26-35 years old, one participant was < 26 years old, and one participant was 56-65 years old. The average age was 32 years old (see Table 1.2 for the gender distribution within each age group). Four out of seven participants had a master degree and three had a bachelor degree. Among the participants, three were not yet connected to the InterConnect service, while four were already connected.

Table 1.2: Gender distribution of participants within age groups.

Age	Gender	
	Male	Female
< 26 years	1 participants	-
26 to 35 years	3 participants	2 participant
36 to 45 years	-	-
46 to 55 years	-	-
56 to 65 years	1 participant	-
> 65 years	-	-

After outlining the objective and duration of the interview, and collecting background information from the participants, they were asked to reflect on the impact of their involvement in InterConnect on both their understanding and behavioral patterns concerning energy consumption. Additionally, they were asked about the extent of their efforts to mitigate energy usage, their overall satisfaction with the appliances offered by InterConnect, their perception of their knowledge level regarding the InterConnect project, and their perspective on the necessity of wider dissemination of these appliances. For a detailed overview of the interview protocol, please see Appendix B.

1.4 Reading Guide

Chapter 2 contains the results of both the quantitative and qualitative research per KPI. Chapter 3 contains the conclusions and recommendations.

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[3] The number of seven interviews was determined by our partners at Yncrea Mediterranee, who are the coordinating party for the societal studies across InterConnect partner countries.

2 Results

In the following, we will present both quantitative as well as qualitative results per KPI:
〉 Rise in energy awareness due to the InterConnect project
〉 Usage of the four smart appliances
〉 Ease of use of the four smart appliances
〉 Satisfaction with the four smart appliances
〉 Perceived value of the four smart appliances.

Additionally, we will provide qualitative insights on complains and suggestions for improvement. For a transcript of all the interviews, please see Appendix C.

2.1 Rise in energy awareness due to the InterConnect project

Overall, the energy awareness of participants due to the InterConnect project, measured by means of sustainable energy consumption, significantly increased over time. However, energy awareness in terms of knowledge of the energy-saving measures implemented in their current home has not significantly increased, but remained high. During the interviews, participants gave mixed responses regarding the direct impact of the InterConnect project their knowledge and behavior regarding energy consumption: while some acknowledged an impact, some expressed scepticism due to lack of familiarity or technical issues.

The rise in energy awareness due to the participation in the InterConnect project was measured by asking the question "Would you describe your energy consumption as sustainable?". During the initial assessment (0-measurement), participants were asked specifically about their energy consumption prior to joining the InterConnect project. After that, in the 1- and 2-measurement, participants were asked about their current energy consumption.

The results indicate that at the 0-measurement stage, 50% of participants described their energy consumption as sustainable (see Figure 2.1). By the 2-measurement, this figure rose to 86%. Notably, during the 1-measurement, all participants described their energy consumption as sustainable. The decrease of 14% from the 1-measurement to the 2-measurement may be due to several reasons, including shifts in perception (participants may have initially been more enthusiastic about sustainable energy consumption compared to later stages), levels of project engagement (participants might have been more actively involved in the project during the second measurement), or external influences such as seasonal variations or individual circumstances.

The rise of energy awareness significantly increased over time. This is confirmed by a one-way between subjects analysis of variance (ANOVA) $F_{(2, 90)} = 16.71$, $p < 0.001$. More specifically, post hoc comparisons using estimated marginal means and Bonferroni adjustments (function emmeans in R package "emmeans") indicate that the rise in energy awareness is evident from the 0-measurement ($M = 1.5$, $SD = 0.5$) to the 1-measurement ($M = 1.0$, $SD = 0.0$) as well as the 2-measurement ($M = 1.1$, $SD = 0.4$). However, the 1-

measurement did not significantly differ from the 2-measurement. Significant differences between measures are indicated in Figure 2.1 by means of a bracket and a star.
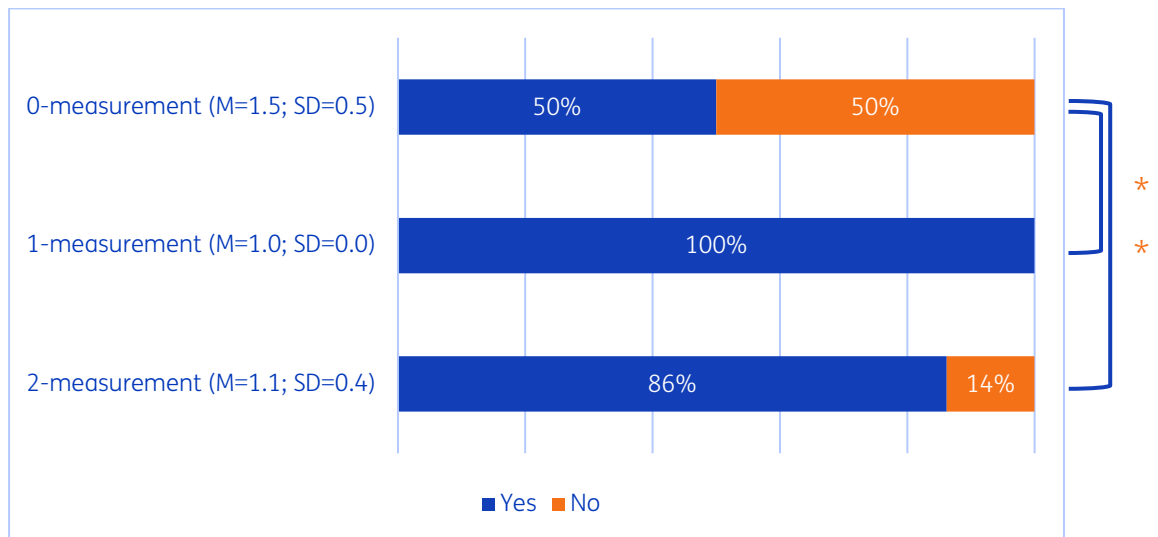
Figure 2.1: Would you describe your energy consumption (before your participation in the Interconnect-project) as sustainable?, $F(2, 90) = 16.71$, $p < 0.001$.

The rise in energy awareness was also assessed by asking participants about their knowledge of the energy-saving measures implemented in their current home. The results indicate that in the 0-measurement, 75% of participants were already aware of the energy-saving measurements that have been taken in their new home (see Figure 2.2). By the 2-measurement, this awareness increased to 83%. While the baseline awareness of energy-saving measures was relatively high, and the disparity between measurements did not reach statistical significance, $F(2, 90) = 0.15$, $p = 0.858$, a slight upward trend is evident.
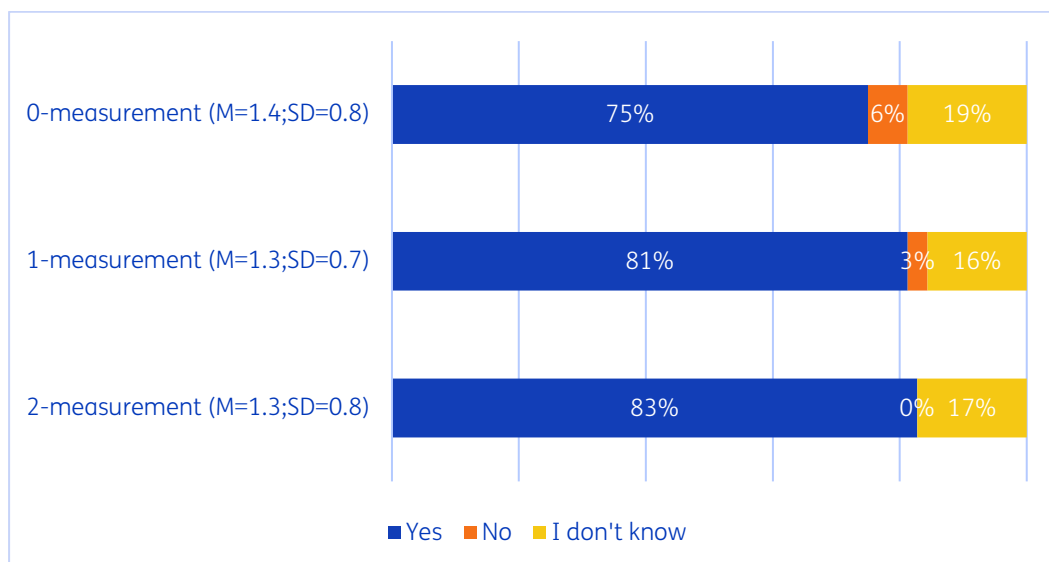
Figure 2.2: Have energy-saving measures been taken in your current home (e.g. by cavity wall insulation, heat pump, high-efficiency glass (HR++ or triple glazing))?, $F(2, 90) = 0.15$, $p = 0.858$.

During the interviews with seven participants of the InterConnect project in November and December of 2023, we asked whether their participation in the project has helped them to improve their knowledge and behavior regarding energy consumption. Some participants acknowledged that their participation in the InterConnect project positively influenced both their knowledge and behavior regarding energy consumption (n=3). One participant answered the question with 'yes and no', elaborating, "*Knowledge yes, as in we knew a bit about our energy consumption, but because of InterConnect we have delved into it a bit more. Our behavior has improved sometimes, but not necessarily always. InterConnect unfortunately doesn't work yet.*" Others expressed scepticism or indicated that their awareness and behavior were not significantly impacted by the project (n=3). Mentioned reasons for that were already existing energy-conscious habits, lack of familiarity with the InterConnect app, or technical issues hindering its functionality.

2.2 Usage of the four smart appliances

Overall, participants showed high awareness of the smart features, particularly for the washing machine, dishwasher, and tumble dryer, but there was lower awareness of the smart features of the automated air ventilation. However, among participants who were aware of the smart features (n=58), adoption and usage rates did not significantly increase over time. On average, the smart features of the washing machine, tumble dryer, dishwasher, and automated air ventilation were utilized by 66%, 64%, 69%, and 73% of those participants, respectively. During the interviews, participants revealed varying efforts to reduce energy consumption, with some expressing proactive engagement and a willingness to adopt additional measures, while others described challenges and occasional disengagement. Nevertheless, the majority of participants expressed a strong willingness to adopt further efforts in energy conservation.

Before asking participants about their usage of the smart features of the four appliances, they were asked to identify those devices that could be used in a smart way among a list of different appliances, including the washing machine, tumble dryer, dishwasher, and automated air ventilation. Results showed high awareness levels among participants for the washing machine (M=93%), dishwasher (M=81%), and tumble dryer (M=77%; see Figure 2.3). However, awareness of the smart features of the automated air ventilation was lower, with less than half of the participants indicating awareness (M=44%).
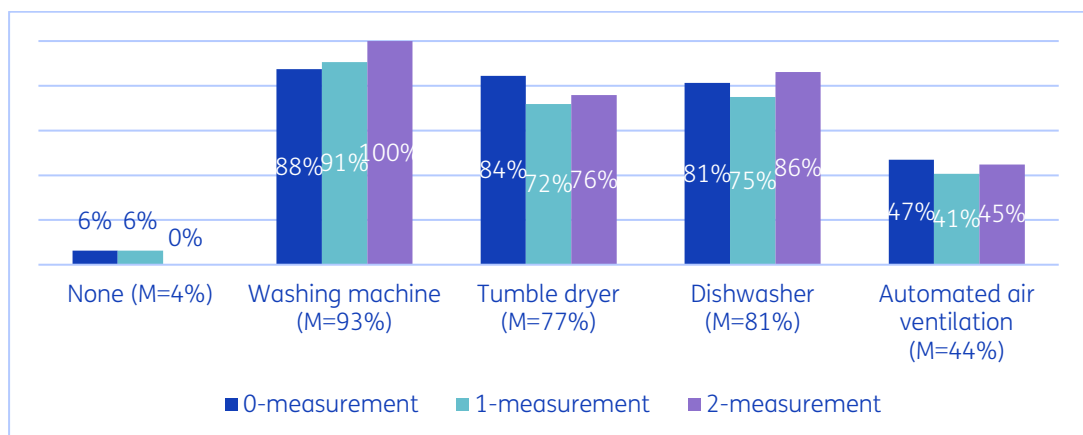

Figure 2.3: Which of the devices below can be used in a smart way (e.g. controlled by an app)?.

After that, participants who indicated awareness of the smart features (N=58) were asked to rate their usage frequency per appliance on a 6-point Likert scale, ranging from "never" to "multiple times a day". This question was only posed during the 1- and 2-measurements since the online activation of smart features took place on July 3rd, 2023 instead of as planned on January 1st, 2023. This was due to technical software issues at the Dutch pilot site.

The results reveal a slight increase in total usage of the smart features[4] from 67% in the 1-measurement to 69% in the 2-measurement for all smart devices. However, for none of the smart appliances, this increase in usage of the smart features was statistically significant, $p > 0.05$ (see Figure 2.4). On average, the washing machine was used by 66% of the participants, the tumble dryer by 64% of the participants, the dishwasher by 69% participants, and the automated air ventilation by 73% participants who indicated awareness of the smart features.
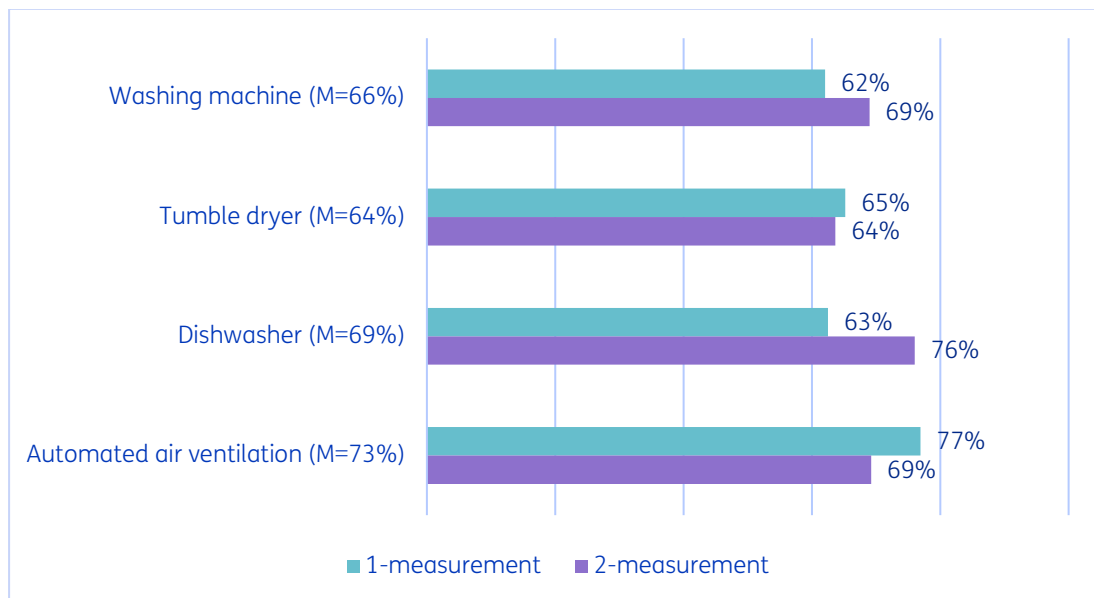

Figure 2.4: How often do you use the smart features with each device or service below? (N=58), $p > 0.05$.

During the interviews, participants' efforts to reduce their energy consumption were assessed on a scale from 1 (no effort) to 10 (significant effort). Responses varied, with some participants expressing proactive efforts (ratings of 8 and 9), actively managing their energy consumption and utilizing the smart features. Others indicated moderate efforts (ratings of 7 and 6), describing challenges such as technological limitations and occasional disengagement. For instance, one participant said, *"We do our best, but sometimes it's just easier to ignore it".* One participant expressed minimal engagement (rating of 3), stating, *"Honestly, my partner and I are not very engaged at the moment. We would like to, but it requires a more active approach."*

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4   The usage of the smart features was determined by summing up responses from participants who indicated using an appliance less than once a week, every week, more than once a week, every day, and multiple times a day. Participants who indicated that they never use the appliance where excluded from the calculation.

In terms of future efforts to reduce energy consumption, the majority of participants expressed a willingness to make additional efforts. Many indicated they would consider utilizing the smart features of the appliances if they proved to be effective. For instance, one participant mentioned, *"When I get started with the InterConnect system and if that has an effect, I will start using it more."* Two participants indicated no plans for further efforts, believing their current actions were sufficient.

2.3 Ease of use of the four smart appliances

Overall, there was a substantial improvement in the ease of use for all four devices, rising from 41% in the 0-measurement to 76% in the 2-measurement, indicating a notable improvement in user experience over time. Specifically, significant improvements in ease of use were found for the washing machine, dishwasher, and automated air ventilation between the 0-measurement and the 2-measurement. However, there was no significant increase in ease of use for the tumble dryer over time.

Ease of use of the four smart appliances was assessed by asking participants to rate the usage of these appliances on a 7-point Likert scale from "very easy" to "very difficult". For the washing machine, ease of use significantly increased from 41% in the 0-measurement, to 75% in de 1-measurement, and to 83% in the 2-measurement, $F_{(2, 90)} = 5.33$, $p = 0.007$ (see Figure 2.5). More specifically, post hoc comparisons indicate that the rise in ease of use is evident from the 0-measurement (M = 3.8, SD = 1.9) to the 2-measurement (M = 2.1, SD = 1.7). However, the 1-measurement (M = 2.8, SD = 2.3) did not significantly differ from the 0- and 2-measurement. The significant difference between measures is indicated in Figure 2.5 by means of a bracket and a star.
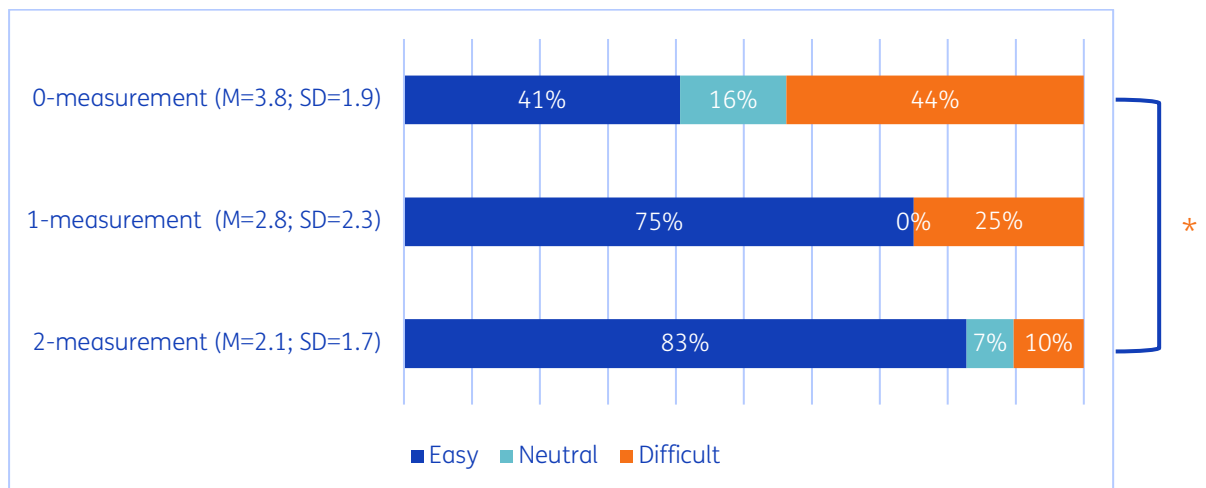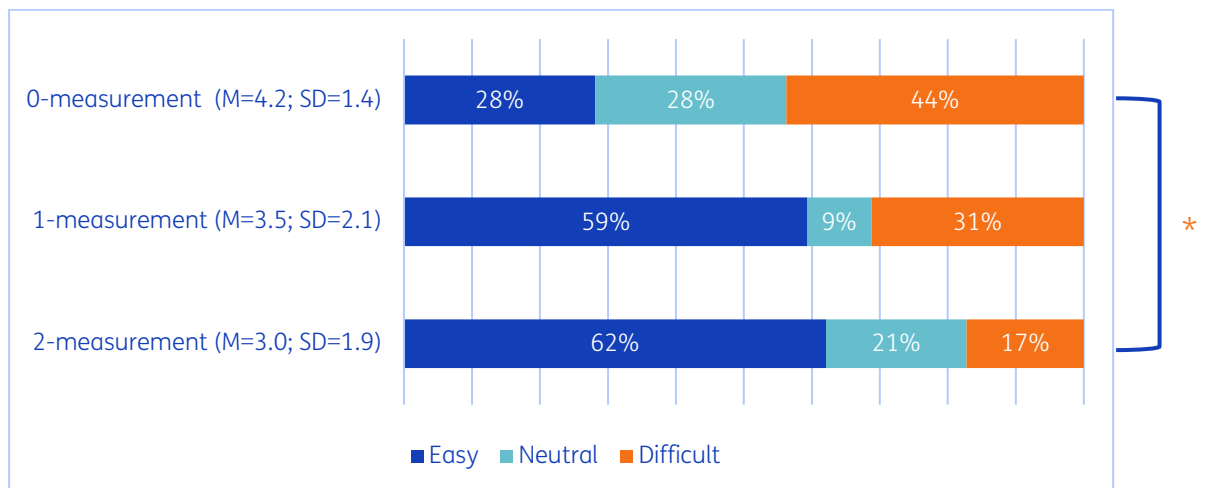

Figure 2.5: How easy to use do you find the following devices and services: Washing machine?, $F_{(2, 90)} = 4.28$, $p = 0.017$.

For the dishwasher, ease of use significantly increased from 44% in the 0-measurement, to 72% in de 1-measurement, and to 79% in the 2-measurement, $F_{(2, 90)} = 4.28$, $p = 0.017$ (see Figure 2.6). More specifically, post hoc comparisons indicate that the rise in ease of use is evident from the 0-measurement (M = 3.8, SD = 2.0) to the 2-measurement (M = 2.4, SD = 1.9). However, the 1-measurement (M = 2.8, SD = 2.2) did not significantly differ from the 0- and 2-measurement. The significant difference between measures is indicated in Figure 2.6 by means of a bracket and a star.
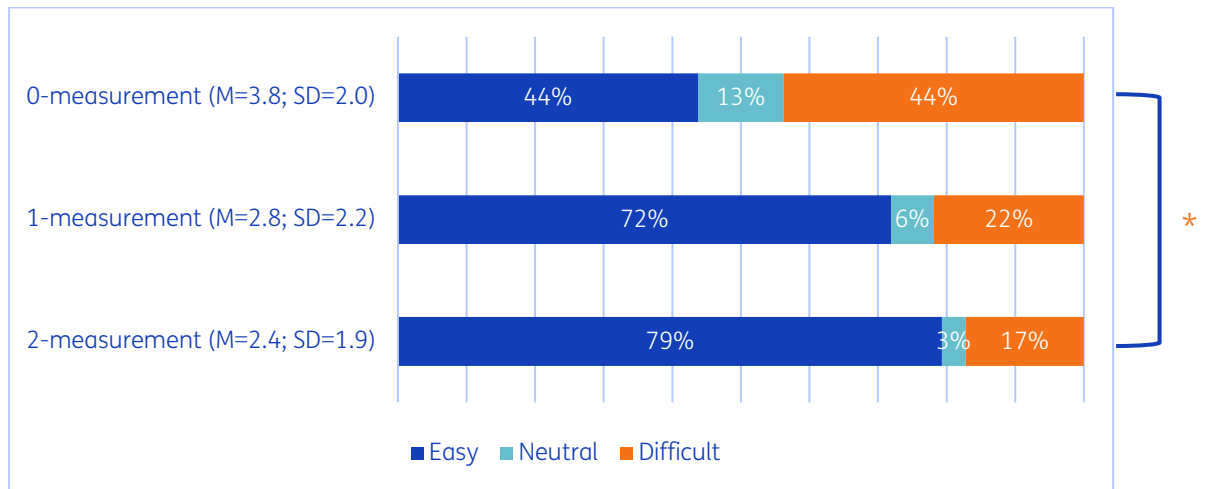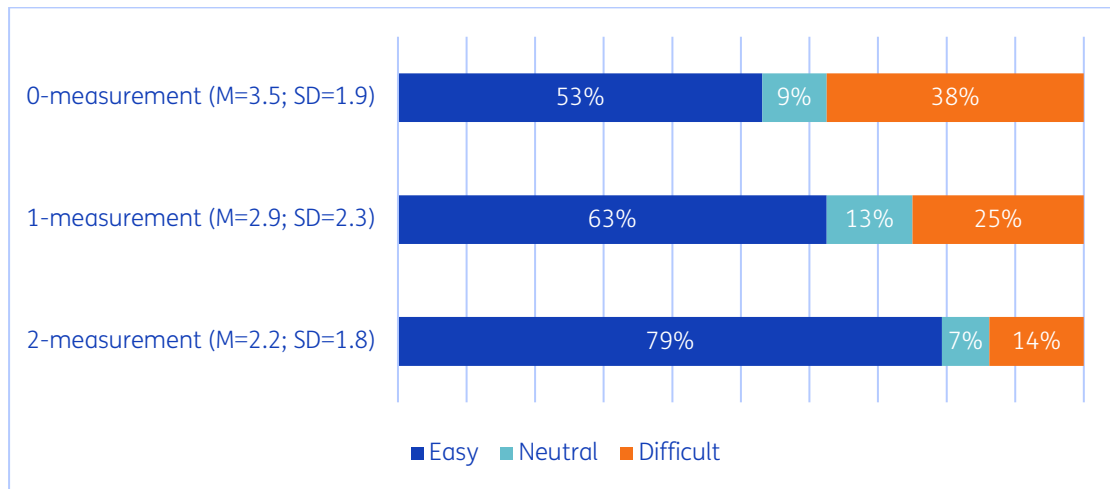
Figure 2.6. How easy to use do you find the following devices and services: Dishwasher?, $F_{(1, 91)}$ = 8.33, p = 0.005.

For the automated air ventilation, ease of use significantly increased from 28% in the 0-measurement, to 59% in de 1-measurement, and to 62% in the 2-measurement, $F_{(2, 90)}$ = 3.5, p = 0.034 (see Figure 2.7). More specifically, post hoc comparisons indicate that the rise in ease of use is evident from the 0-measurement (M = 4.2, SD = 1.4) to the 2-measurement (M = 3.0, SD = 1.9). However, the 1-measurement (M = 3.5, SD = 2.1) did not significantly differ from the 0- and 2-measurement. The significant difference between measures is indicated in Figure 2.7 by means of a bracket and a star.

Figure 2.7. How easy to use do you find the following devices and services: Automated air ventilation?, $F_{(2, 90)}$ = 3.5, p = 0.034.

There was no significant increase in ease of use for the tumble dryer over time, $F_{(2, 90)}$ = 2.9, p = 0.060, but a slight trend upwards is evident (see Figure 2.8).

Figure 2.8. How easy to use do you find the following devices and services: Tumble dryer?, $F(2, 90) = 2.9$, $p = 0.060$.

2.4   Satisfaction with the four smart appliances

Overall, the assessment of satisfaction with the four smart appliances unveiled significant improvements across various metrics. Notably, the Net Promoter Score (NPS) showcased substantial enhancements for the washing machine, tumble dryer, and dishwasher, particularly evident between the 0- and 1-measurements. Despite an initially low NPS, the automated air ventilation system also displayed progress over time. Asking participants directly about satisfaction revealed statistically significant improvements for the dishwasher, washing machine and tumble dryer. During the interviews participants revealed varying satisfaction levels, partially influenced by their lack of usage of the InterConnect system.

Satisfaction with the four smart appliances within the InterConnect project was measured my multiple metrics: the Net Promoter Score and a direct question about satisfaction. Satisfaction with products are commonly measured by the Net Promoter Score (NPS), which is calculated by asking consumers a single question: "On a scale from 0 to 10, how likely would you be to recommend the below devices and/or services present in your household to your friends, family or colleagues?" The responses are then categorized into three groups: promoters (score 9-10), passives (score 7-8), and detractors (score 0-6). The NPS is calculated by subtracting the percentage of detractors from the percentage of promoters, reported with a number ranging from -100 to +100. This provides a straightforward metric for assessing customer satisfaction, with higher scores indicating greater satisfaction and likelihood of recommendation.

In the current study, the NPS for each of the four smart appliances was assessed during all of the three measurement phases (see Table 2.1). The NPS for the washing machine demonstrated an increase of 42 points between the 0- and 2-measurements, with an even higher score of 53 at the 1-measurement. Similarly, the NPS of the dishwasher experienced an increase of 41 points, peaking at 44 at the 1-measurement. For both appliances, the slightly higher scores in the 1-measurement may be due to various factors, such as technical issues or shifts in perceptions about the appliances. For the tumble dryer, the NPS demonstrated a rise by 42 points between the 0- and 2-measurements. Conversely, the

automated air ventilation started with a quite low NPS of -50 at the 0-measurement, which improved to -17 at the 2-measurement.

In total, the NPS of all four smart appliances taken together has increased from -13 points in the 0-measurement to 29 points in the 1-measurement and remained quite stable with 28 points in the 2-measurement.

Table 2.1: Net promotor scores (NPS) per smart device per measurement.

	0-measurement	1-measurement	2-measurement
Washing machine	3	53 (+50)	45 (+42)
Tumble dryer	-6	38 (+44)	41 (+47)
Dishwasher	0	44 (+44)	41 (+41)
Automated air ventilation	-50	-19 (+31)	-17 (+33)
Total	-13	29 (+40)	28 (+39)

Additionally, we asked participants to rate their satisfaction with each device on a 7-point Likert scale from "not at all satisfied" to "very satisfied" during each measurement. Results reveal that satisfaction significantly increased from 75% in the 0-measurement to 97% in the 1-measurement and 93% in the 2-measurement for both the washing machine, $F_{(2, 90)}$ = 5.58, p = 0.005 (see Figure 2.9), and the dishwasher, $F_{(2, 90)}$ = 6.72, p = 0.002 (see Figure 2.10). For the tumble dryer, satisfaction significantly increased from 75% in the 0-measurement, to 94% in the 1-measurement and 90% in the 2-measurement, $F_{(2, 90)}$ = 4.45, p = 0.014 (see Figure 2.11). The slightly higher satisfaction scores in the 1-measurement compared to the 2-measurement may again be due to various factors, such as technical issues during the 2-measurement or shifts in perceptions about the appliances. With an increase from 53% in the 0-measurement to 66% in the 2-measurement, satisfaction did not significantly increase for the automated air ventilation, $F_{(2, 90)}$ = 1.26, p = 0.29 (see Figure 2.12).

More specifically, post hoc comparisons for the washing machine, the dishwasher and the tumble dryer, indicate that the rise in satisfaction is evident from the 0-measurement (washing machine: M = 5.7, SD = 1.3; dishwasher: M = 5.6, SD = 1.2; tumble dryer: M = 5.6, SD = 1.4) to the 1-measurement (washing machine: M = 6.6, SD = 0.8; dishwasher: M = 6.4, SD = 0.8; tumble dryer: M = 6.5, SD = 0.9). For the dishwasher, the rise in satisfaction is also evident from the 0-measurement to the 2-measurement (M = 6.3, SD = 0.9). This was, however, not the case for the washing machine (M = 6.3, SD = 1.0) and the tumble dryer (M = 6.0, SD = 1.2). The significant differences between measures are indicated in each figure by means of a bracket and a star.
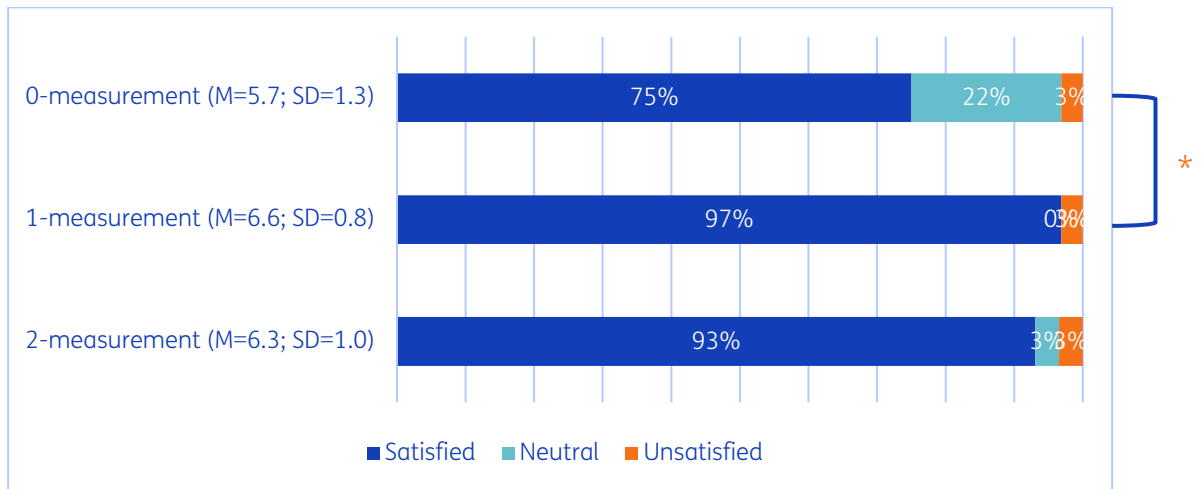
Figure 2.9. How satisfied are you with each device or service below: Washing machine?, $F(2, 90) = 5.58$, $p = 0.005$.
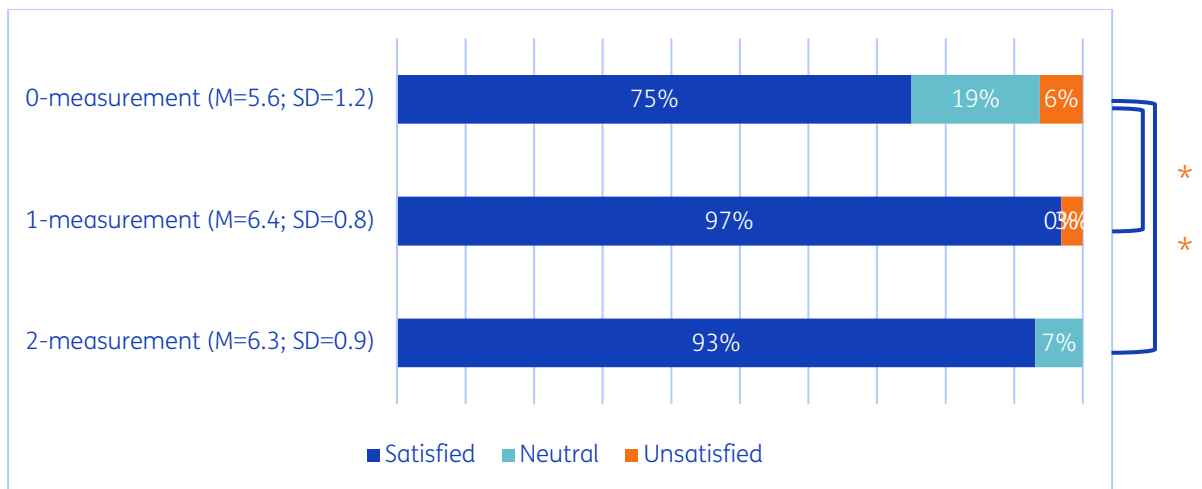

Figure 2.10. How satisfied are you with each device or service below: Dishwasher?, $F(2, 90) = 6.72$, $p = 0.002$.
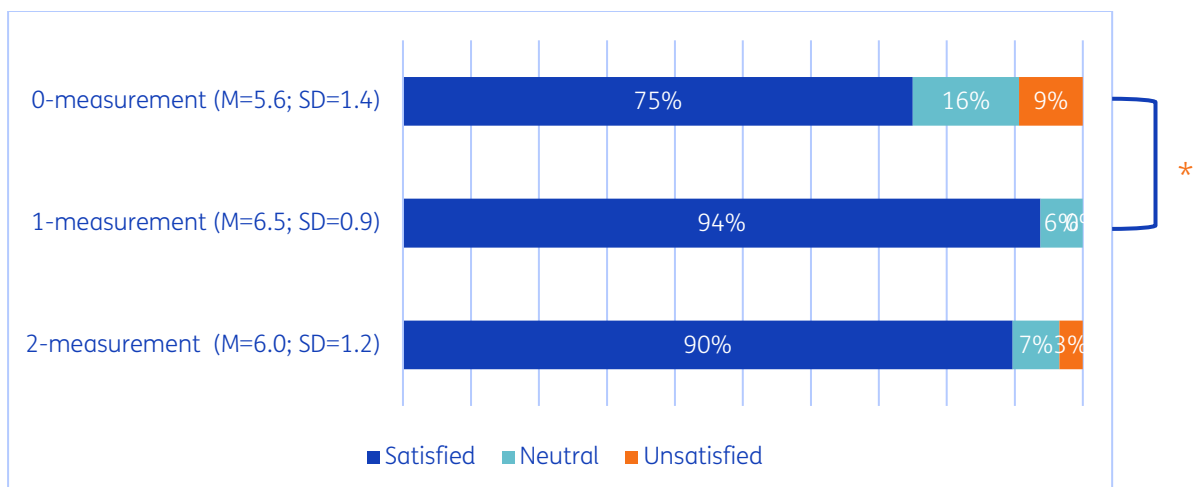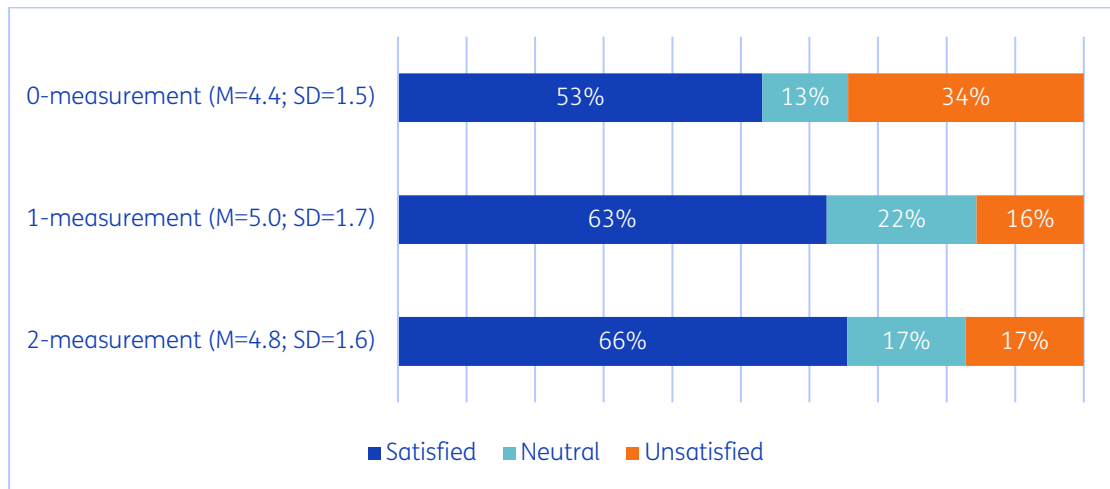

Figure 2.11. How satisfied are you with each device or service below: Tumble dryer?, $F(2, 90) = 4.45$, $p = 0.014$.

Figure 2.12. How satisfied are you with each device or service below: Automated air ventilation?, $F_{(2, 90)}$ = 1.26, p = 0.29.

During the interviews, we assessed the participants' satisfaction with the smart appliances provided by InterConnect using a scale ranging from 1 (not at all satisfied) to 10 (fully satisfied). The results reveal variability in participants' satisfaction levels: three participants rated their satisfaction neutrally at 5, while three other participants expressed high satisfaction with ratings of 8 or 9. One participant gave a low rating of 1 or 2 points due to technical issues with InterConnect. In general, participants who reported high satisfaction levels often cited the user-friendly website interface and overall contentment despite initial startup challenges. Conversely, lower satisfaction ratings stemmed from concerns such as a perceived lack of noticeable impact, communication issues, or impartiality due to not yet using InterConnect.

2.5 Perceived value of the four smart appliances

Overall, the perceived value of the four smart appliances slightly increased from 84% in the 0-measurement to 85% in the 2-measurement. These changes were not statistically significant. On average, the washing machine, dishwasher, tumble dryer, and automated air ventilation were valued by 98%, 95%, 82%, and 67% of participants, respectively. During the interviews, participants provided varied responses regarding any observed decrease in energy consumption since the start of the InterConnect project. Some reported stable costs, while others expressed uncertainty due to a lack of comparative data.

The perceived value of the four smart appliances within the InterConnect project was assessed by asking participants to rate their agreement with statements reflecting the value of each smart device in their household, using a 7-point Likert scale ranging from "strongly disagree" to "strongly agree". The results indicate that there was no significant increase in perceived value for any of the smart appliances, $p > 0.05$ (see Figure 2.13). On average, the washing machine received the highest ratings, deemed valuable by 98% of the participants, followed by the dishwasher at 95% and the tumble dryer at 82%. Conversely, the automated air ventilation received lower ratings, with only 67% of the participants considering it valuable.

The lack of significant increase in perceived value may be attributed to the already high ratings observed in the 0-measurement for most of the smart appliances which in turn may be due to the nature of the appliances (e.g., a washing machine is useful and valuable in every household).
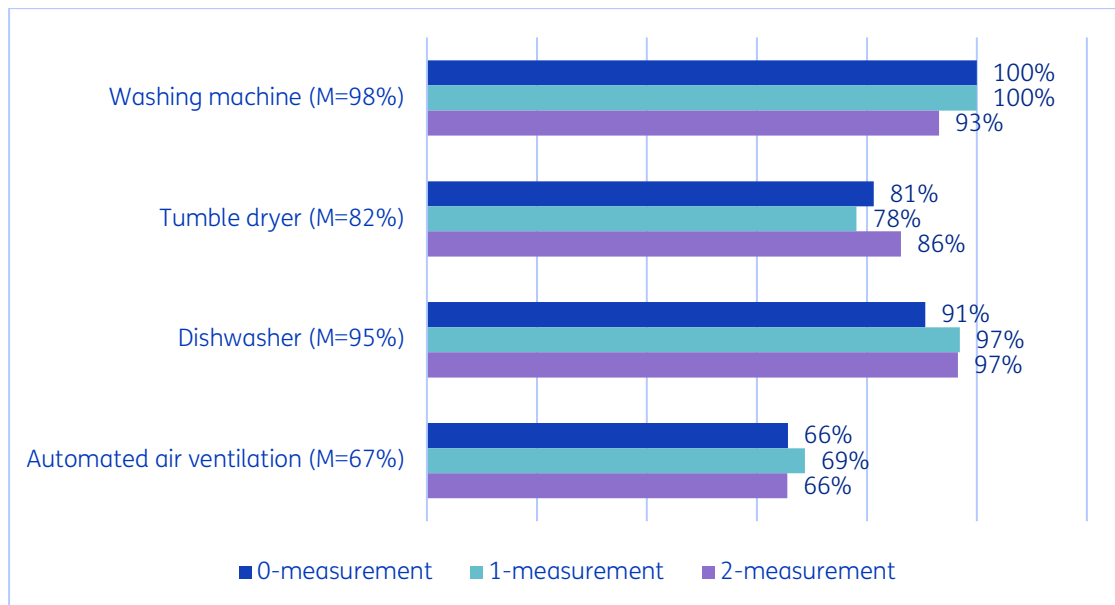
Figure 2.13. To what extent do you agree with the following statements? The [smart appliance] in my current home is a valuable/ useful element in my household, $p > 0.05$.

During the interviews, participants were asked about any observed decrease in energy consumption since the initiation of the InterConnect project. Overall, responses varied. Some participants reported stable costs, with one noting, *"I haven't noticed any decline in costs, but I have noticed that costs remain stable."* Others expressed uncertainty due to a lack of comparative data, with one participant remarking, *"I don't have a comparison with before we moved into this building either."* Furthermore, participants conveyed curiosity about potential future reductions in energy consumption upon integration with InterConnect, indicating a readiness to gain deeper insights into their usage patterns.

2.6 Complaints and suggestions for improvement

During the interviews with seven participants, several complaints and suggestions for improvement were raised. While it is important to note that these issues and suggestions were only mentioned by one or two participants each, they nonetheless provide valuable insights into the satisfaction and usage of the smart appliances within InterConnect. Additionally, they offer inspiration for further improvement in the project.

Overall, the findings indicate that certain interviewees had complaints regarding the user experience, particularly with the functionality of the appliances. Others voiced concerns about the overwhelming amount of information received via email and the challenges associated with managing multiple apps. In terms of recommendations, participants suggested improving the dissemination of information, especially regarding the impact of

energy-saving endeavors, cost differentials between utilizing InterConnect and manual operation, and the ratio of green energy utilization. Additionally, they proposed integrating features such as a power outlet for manual device incorporation and incorporating home batteries and electric cars into the InterConnect system to enhance energy efficiency and charging capabilities.

The participants expressed several complaints regarding the InterConnect project:

1. **Unawareness of and difficulty with device buttons**
   Two participants were unaware of, and complained about not having buttons on the devices themselves. For example, one participant noted, *"With the dishwasher, it would be easier if I could set a fixed time. Now I have to go to the app first to set the times there. I would prefer to be able to set the times on the dishwasher itself."* Another mentioned, *"Our lamps in the kitchen and living room are linked, so if e.g. you want to switch on the lamp in the living room but not in the kitchen, you can't do this via the button but only via the app."*.

2. **Information overload via mail**
   Third, one participant complained about the information overload via mail, saying *"It would be good to realize that it could come across as an information overload."*.

3. **Too many apps**
   Finally, one participant complained about the among of apps necessary, saying *"It feels like it's very complicated now – maybe because it doesn't work at the moment, but also because different devices need to be connected to different apps."*.

The participants provided several suggestions regarding the product- as well as service-design surrounding the four smart appliances:

1. **More information...**
   a. **...on impact:** One participants suggested providing more information on the impact of their energy-saving efforts: *"I would like to be more informed about my impact on environmental goals - also about the savings and impact of the whole apartment complex ('you have saved X, this is the biggest savings you can still achieve'). This would encourage me and others to do even more: 'If you do this and this, you can save this and that'. But also, 'How does it compare at Strijp S with all the flats?' Perhaps another newsletter about what can be achieved with InterConnect. 'Did you know that X€ can be saved on a monthly/annual basis?'."* This participant also recommended installing a display screen in the entrance hall, saying, *"seems like an ideal means of displaying all the information."* However, they also noted concerns about vandalism and suggested adding surveillance or placing the screen behind glass.
   b. **...on difference in cost:** Another participants expressed a desire to receive more information on the difference in cost between using InterConnect and their own chosen time, mentioning, *"It would be nice, however, if you could see the difference in the use between the time chosen from InterConnect and the time you would choose yourself."*
   c. **...on percentage of green energy:** Another suggestion was to provide more information on and choice in the percentage of green energy, as one participant noted, *"There is too little information about the percentage of green energy and grey energy at the moment I use the appliances."*

2. **Power outlet to manually add devices to InterConnect:** One participant also suggested adding a power outlet to manually add devices to the InterConnect system, with one mentioning the need for controlling power-hungry appliances such as air conditioners.

3. **Connecting a home battery and electric cars to InterConnect:** Connecting a home battery to InterConnect was proposed as a feature to fully schedule power usage during off-peak times, with one participant stating, *"Another feature I would like is being able to connect a home battery to InterConnect."* The same participants expressed interest in connecting electric cars to InterConnect, stating, *"I would like a solution for my electric car [...] it would be an interesting business case if the electric cars could also be charged in the garage."*

3 Conclusions and Recommendations

3.1 Conclusions

Overall, this study demonstrates the successful implementation of the four smart appliances in the Next building in Eindhoven. However, usage of the delayed start feature is still limited to a small number of individuals who are aware of its existence and has not significantly increased over time. Nonetheless, participants have shown increased energy awareness, and their satisfaction and ease of use with the appliances have significantly improved. The following six conclusions can be drawn from these findings.

Energy awareness increased significantly, while knowledge about energy-saving measures remained high
Energy awareness showed a notable increase, with participants reporting a 36% rise in their perception of energy consumption sustainability following their engagement in the InterConnect project (see Table 3.1). Despite this, participants demonstrated consistently high knowledge levels around 80%, regarding energy-saving measures in their homes. During interviews, participants offered mixed feedback on the project's direct impact on energy awareness, with three participants acknowledging a positive influence on both their understanding of energy consumption and related behaviors. Three participants cited factors such as pre-existing energy-conscious habits, limited familiarity with the InterConnect app, or technical challenges hindering its functionality as reasons for their unchanged awareness levels.

Despite high awareness of the smart features (especially for the white goods), usage did not increase over time
Participants were highly aware of the smart features, especially regarding the white goods, including the washing machine (93%), dishwasher (81%), and tumble dryer (77%). Awareness of the automated air ventilation's smart features was lower (44%). Despite this awareness, usage rates among participants who were aware of these features did not increases over time (see Table 3.1). On average, the smart features of the washing machine, tumble dryer, dishwasher, and automated air ventilation were utilized by 66%, 64%, 69%, and 73% of those participants, respectively. Interviews with participants revealed diverse efforts to reduce energy consumption, ranging from proactive engagement to encountering challenges and occasional disengagement. Nevertheless, a majority of participants expressed a strong willingness to embrace additional measures for energy conservation.

Ease of use of the white goods significantly increased
The ease of use for all smart appliances notably increased 35% from 41% in the initial measurement to 76% in the final measurement (see Table 3.1). Specifically, the washing machine (42%), dishwasher (35%), and automated air ventilation (35%) demonstrated significant improvements in ease of use from the first to the last measurement. While there was no significant increase in ease of use for the tumble dryer over time (26%), an upward trend is evident.

Likelihood of recommendation for each smart appliance and satisfaction with the white goods significantly increased

Satisfaction with the smart appliances, as evaluated through Net Promoter Scores (NPS) for each device, demonstrated substantial enhancements over time, increasing by 39 points on a scale from -100 to 100 (see Table 3.1). Direct questions about satisfaction with each smart device revealed that especially the satisfaction with white goods, including the washing machine, dishwasher and tumble dryer, increased significantly by 22%, 22% and 19%, respectively from the initial measurement to the subsequent one. Satisfaction about the automated air ventilation remained relatively unchanged. Further insights from interviews revealed divergent satisfaction levels among participants, partially influenced by varying degrees of engagement with the InterConnect system.

Perceived value of the smart devices remained high

The perceived value of the four smart appliances, measured by asking participants to reflect on the value of each smart appliance, remained consistently high at around 85% (see Table 3.1). While the washing machine was valued the most with 98%, the automated air ventilation was valued least with 67%. During the interviews, participants provided varied responses regarding the perceived decrease in energy consumption since the start of the InterConnect project. Some reported stable costs, while others expressed uncertainty due to a lack of comparative data.

Table 3.1: Overview of results per KPI.

KPI	Calculation	Result
Rise in energy awareness	KPI = 2-measurement – 0-measurement	⬆ +36%
Usage	KPI = 2-measurement (total) – 1-measurement (total)	⬆ +2%
Ease of use	KPI = 2-measurement (total) – 0-measurement (total)	⬆ +35%
Satisfaction	KPI = 2-measurement (total) – 0-measurement (total)	⬆ +39
Perceived value	KPI = 2-measurement (total) – 0-measurement (total)	⬆ +1%

Participants revealed limited knowledge about the functionality of the smart feature and complained about too many emails and the high amount of apps

Concerns were raised regarding the absence or difficulty of using the physical buttons on the smart devices to control the smart feature, indicating a lack of knowledge among the participants. Additionally, participants complained about too many emails and about the high number of apps required for system management. Although these observations were based on a limited number of participants, they offer valuable insights into the challenges experienced by users.

3.2 Recommendations

To enhance user experience and maximize the benefits of the InterConnect project, several recommendations have been identified based on participant feedback and performance metrics.

Provide user training and support
In order to close existing knowledge gaps on using the smart feature as well as via the physical buttons, as indicated by some interviewees, we recommend to provide comprehensive training and support materials to ensure users can fully utilize smart feature effectively. By offering for example interactive workshops, online tutorials, and establishing dedicated support channels, such as help desks or online forums, users can receive the assistance they need to optimize their use of the smart appliances.

Provide information about impact, difference in cost and percentage of green energy, for example via a display in the entrance hall of the building
As indicated by the interviewees, participants want more information on the environmental impact of the InterConnect project and energy savings achieved through participants' efforts, for both their own apartment as well as the whole apartment complex. Participants are also curious about the cost differences between using InterConnect and participants' preferred timing for energy consumption. Finally, participants are curious about the percentage of green energy consumed versus grey energy. Consider implementing a display screen in communal areas (incl. extra protection against vandalism) to showcase real-time energy usage data and savings. This information and transparency can empower users to make informed decisions about their energy usage.

Streamline communication
Reduce information overload by streamlining communication channels and ensuring that information sent via email is concise, relevant, and actionable. Consider consolidating information into fewer emails or providing customizable preferences for receiving updates.

Investigate possible issues with the automated air ventilation
Compared to the other devices, the automated air ventilation has a low NPS (-17), a lower satisfaction score (66%) and perceived value score (67%). We therefore recommend to investigate into the specific issues or concerns related to the automated air ventilation system. A first indicator of possible factors contributing to the lower satisfaction and perceived value scores is the low awareness of the smart features of this device (44%) compared to the other devices. Other factors include technical issues, usability challenges, or inadequate performance compared to user expectations. By gaining more insights about the automated air ventilation, enhancements can be made to improve the user satisfaction and perceived value of this device.

Technical improvements: integration of other devices into InterConnect
Explore opportunities of introducing a power outlet feature within the InterConnect system, enabling users to manually add and control additional devices. This flexibility enhances user autonomy and control over energy usage. Specifically, participants are interested in the integration of home batteries and electric cars.

Appendix A
Overview questionnaires

In the following, we will provide an overview of the questionnaires utilized in the current study, which was inspired and is closely related to the questionnaires designed by our InterConnect partners at Yncrea Mediterranee. Sentences and questions exclusive to the 0-measurement are highlighted in blue, while those exclusive to the 1- and 2-measurements are highlighted in orange. In case applicable, the filters for each question are highlighted in purple.

Welcome!
This questionnaire is part of the EU project Interconnect (Interconnect Project - Homepage). The main goal of the Interconnect project is to make energy use as smart as possible by developing solutions that connect smart homes, buildings, and electricity grids. Part of the project is also a behavioural study conducted by TNO. During the study, you will be asked to complete a questionnaire at three occasions:

- when you start the Interconnect project;
- after six months of participation in the Interconnect project;
- and at the end of the Interconnect project.

The questions concern how much energy you use, how satisfied you are with the products and appliances offered by BouwInvest and whether you use these products and appliances in your daily life. The questionnaire will also ask you to provide some personal data: age, gender, education, occupation, and composition of your household. If you decide to participate, we ask for your consent for the processing of this data. It takes about 10 minutes to complete each questionnaire.

Participation in the study is entirely voluntary. You can stop at any time without having to give a reason. Data from any previously completed questionnaires will remain available for the study, unless you request that these data be deleted.

Processing of your personal data
Your personal data and the results of the study will be treated confidentially. The questionnaire will be administered via Survalyzer. This is an online tool used by TNO for data collection. TNO has made the necessary agreements with Survalyzer to comply with privacy legislation.

To link your answers to the three questionnaires, you will be asked to compile your own code so that your answers are not directly traceable. The answers will be encrypted and shared with the project partners of the EU project Interconnect, in order to facilitate comparisons with other European pilots.

Your personal data and survey results are stored in a secure environment to which only authorised persons/researchers have access. After completion of the study, your data will be stored at TNO until December 2024, after which it will be destroyed.

If you have any questions or comments about the study, please email the following address: luise.schlindwein@tno.nl. You can stop your participation in this study at any time by sending an e-mail to the same address. More information about your privacy rights and how TNO handles your data can be found online in TNO's privacy statement. You will also find the contact details of TNO's Data Protection Officer there.

○ I have read the above information and hereby consent to the processing of my personal data.

No consent means exclusion.

1. To link your data by questionnaire and ensure that your personal data is not directly traceable, we would like to ask you to create a code based on the following questions:

   1. First letter of your first name (e.g. A for Anna)
   2. The day of your date of birth (e.g. 1 for 1 June 1985)
   3. First letter of your place of birth (e.g. A for Amsterdam)
   4. Number of siblings (e.g. 0 if you have no siblings)
   The code emerging from the examples is: A1A0

   What is your personal code?
   _____

The following questions are about the flat you recently moved into.
First, we would like to ask you some general questions about your apartment.

2. Do you know whether one or more of the following energy sources contribute to your power supply (grid power or your own equipment)? Multiple answers possible.
   ☐ Solar panels
   ☐ Geothermal energy
   ☐ Wind turbines
   ☐ Biomass
   ☐ Hydraulic
   ☐ None of the above (exclusive)
   ☐ I don't know (exclusive)

3. Have energy-saving measures been taken in your current home (e.g. by cavity wall insulation, heat pump, high-efficiency glass (HR++ or triple glazing))?
   ○ Yes
   ○ No
   ○ I don't know

4. You indicate that energy-saving measures have been taken in your current home. Which energy-saving measures are they?
   Filter: if 'yes' was chosen in question 3
   _____

5. Which type of heating system do you think is currently installed in your home? Multiple answers possible.
   ☐ Central heating
   ☐ Independent gas boiler
   ☐ Independent oil boiler
   ☐ Independent wood/pellet/coal boiler
   ☐ Heat pump
   ☐ Independent electric heating
   ☐ I don't know (exclusive)

6. How is your hot tap water produced in your current home?
   ○ Electric boiler
   ○ Heat pump
   ○ Individual boiler
   ○ District heating system
   ○ I don't know

7. Which appliances do you have? Multiple answers possible
   ☐ Washing machine
   ☐ Tumble dryer
   ☐ Electric oven
   ☐ Microwave oven
   ☐ Cooking plates
   ☐ Extractor hood
   ☐ Dishwasher
   ☐ Refrigerator
   ☐ Freezer
   ☐ Automated air ventilation
   ☐ None of the above (exclusive)

8. Based on your first impression, how satisfied are you with each device or service below?

	Not at all satisfied 1	2	3	4	5	6	Very satisfied 7
Washing machine	○	○	○	○	○	○	○
Tumble dryer	○	○	○	○	○	○	○
Dishwasher	○	○	○	○	○	○	○
Automated air ventilation	○	○	○	○	○	○	○

9. Based on your first impression, how likely would you be to recommend the below devices and/or services present in your household to your friends, family, or colleagues?'

	Not likely at all 0	1...	...9	Very likely 10
Washing machine	O	O	O	O
Tumble dryer	O	O	O	O
Dish-washer	O	O	O	O
Auto-mated air ventila-tion	O	O	O	O

10. Which of the devices below can be used in a smart way (e.g. controlled by an app)? Multiple answers possible.
    - ☐ Washing machine
    - ☐ Tumble dryer
    - ☐ Electric oven
    - ☐ Microwave oven
    - ☐ Cooking plates
    - ☐ Extractor hood
    - ☐ Dishwasher
    - ☐ Refrigerator
    - ☐ Freezer
    - ☐ Automated air ventilation
    - ☐ None of the above (exclusive)

10a. How often do you use the smart features with each device or service below?

	Never	< once a week	Every week	> once a week	Every day	Multiple times a day
Washing ma-chine	O	O	O	O	O	O
Tumble dryer	O	O	O	O	O	O
Dishwasher	O	O	O	O	O	O
Automated air ventila-tion	O	O	O	O	O	O

10b. You indicated that you do not use the smart functionalities with any of the devices or services. Can you explain why?
Filter: if 'never' was chosen for all devices or services in question

_____

11. Based on your first impression, to what extent do you agree with the following statements?

	Strongly disagree 1	2	3	Neutral 4	5	6	Strongly agree 7
The washing machine in my current home is a valuable/ useful element in my house-hold.	O	O	O	O	O	O	O
The tumble dryer in my current home is a valuable/ useful element in my house-hold.	O	O	O	O	O	O	O
The dish-washer in my current home is a valuable/ useful element in my house-hold.	O	O	O	O	O	O	O
The auto-mated air ven-tilation in my current home is a valuable/ useful element in my house-hold.	O	O	O	O	O	O	O

The following questions are about your energy management, both before the Interconnect project and in the flat you recently moved into.
The following questions are about your energy management in your current apartment.

12. What form of energy contract do you <u>currently</u> have?
    O Fixed energy contract for one or two years
    O Variable energy contract
    O Energy-per-hour contract
    O Other, namely: _____
    O I don't know

13. What form of energy contract would you like to have?
    O Fixed energy contract for one or two years
    O Variable energy contract
    O Energy-per-hour contract
    O Other, namely: _____
    O I don't know

14. Do you have an energy contract with a day/night tariff or similar double tariff?
    ○ Yes
    ○ No
    ○ I don't know

15. Did you pay attention to the day/night tariff (double tariff) before the Interconnect project in case your provider offered it?
    ○ Yes
    ○ No
    ○ My provider didn't offer double tariff

15a. Do the appliances in your current apartment allow you to make better use of the hours when electricity is cheaper?
    ○ Yes
    ○ No
    ○ This is not offered to me

16. Which of the following (possibly temporary) measures to reduce energy consumption have you already taken in your household before the Interconnect project? Multiple answers possible.
    ☐ Switching off devices or services
    ☐ Reducing the power consumption of devices or services
    ☐ Configuring devices or services
    ☐ Shorter usage of devices or services
    ☐ Avoiding usage of devices or services
    ☐ Only use devices or services (e.g. dishwasher or washing machine) at full load/power
    ☐ Choosing the time of usage
    ☐ I have not taken any of these measures (exclusive)

17. Have you used smart / connected electrical devices or services before participating in the Interconnect project?
    ○ Yes, namely: _____
    ○ No

17a. Has the InterConnect project inspired you to use additional smart/connected electrical devices or services?
    ○ Yes, namely: _____
    ○ No

18. Before participating in the Interconnect project, did you use an app to track and manage your energy consumption?
    ○ Yes
    ○ No

18a. Do you feel that your energy consumption is better controlled and managed thanks to the devices and services of the InterConnect project?
- ○ Yes
- ○ No

19. What tools do you have to monitor your energy consumption in your current home? Multiple answers possible.
- ☐ Detailed bill (per device per month)
- ☐ Smart meter
- ☐ Mobile app
- ☐ Home display (smart display to manage energy, among other things)
- ☐ Other, namely: _____
- ☐ None of the above

19a. How satisfied are you with the Loxone app that allows you to track and manage your energy consumption?
- ○ Completely dissatisfied
- ○ Dissatisfied
- ○ A little bit dissatisfied
- ○ Neutral
- ○ A little bit satisfied
- ○ Satisfied
- ○ Completely satisfied

19b. How often do you use the following tools to monitor your energy consumption?

	Never	< once a week	Every week	> once a week	Every day	Multiple times a day
Breakdown bill (per device per month)	○	○	○	○	○	○
Smart meter	○	○	○	○	○	○
App (on mobile phone or iPad)	○	○	○	○	○	○

20. In which ways do you use the heating system in your current home to save energy?
- ○ Choosing a fixed temperature
- ○ Turning down the heater and wearing warm clothes
- ○ Only heat when someone is present
- ○ Other, namely: _____
- ○ I don't use my heating in a way that would save energy

20a. Have your habits regarding the use of your heating changed since you moved into your current apartment?
- ○ Yes, namely: _____
- ○ No
- ○ I don't know

21. Would you describe your energy consumption before your participation in the Interconnect-project as sustainable?
    ○ Yes
    ○ No

22. What was your main motivation to participate in the Interconnect project?
    ○ To save money
    ○ Because I am interested in technology
    ○ To participate in a research study
    ○ To achieve a higher comfort level
    ○ Other, namely: _____

The following questions are about the comfort in your flat that you have recently moved into.
The following questions are about the comfort in your apartment.

23. How would you describe the overall comfort level of your current home?
    ○ Very comfortable
    ○ Comfortable
    ○ Neutral
    ○ Not comfortable enough
    ○ Not comfortable at all

24. Based on your first impression, how easy to use do you find the following devices and services?

	Very easy 1	2	3	Neutral 4	5	6	Very diffi-cult 7
Washing machine	○	○	○	○	○	○	○
Tumble dryer	○	○	○	○	○	○	○
Dishwasher	○	○	○	○	○	○	○
Automated air ventilation	○	○	○	○	○	○	○

25. Do you experience technical problems when heating your home? Multiple answers possible.
    ☐ The heating system is not adapted to my needs
    ☐ There is a lack of insulation
    ☐ It takes too long to reach the desired temperature
    ☐ Poor management
    ☐ Other, namely: _____
    ☐ I don't have problems heating my home (exclusive)

26. You indicated earlier that you have a day/night tariff or similar double tariff. Do you experience any restrictions because of this (e.g. because the times of the low tariff are too short or not practical or because the benefit is too small)? Do you feel that InterConnect's devices and services help with possible restrictions associated with day/night tariff or similar double tariff?
    Filter: if 'yes' was chosen in question 14
    ○　Yes
    ○　No

27. You indicate that you experience restrictions due to a day/night tariff or similar double tariff. Can you indicate exactly what these restrictions are?
    Filter: if 'yes' was chosen in question 26
    _____

28. Did you own one or more electric vehicles before the start of the Interconnect project? Do you own one or more electric vehicles? Multiple answers are possible.
    ☐　Yes, an electric bike
    ☐　Yes, an electric scooter
    ☐　Yes, an electric car
    ☐　Other, namely: _____
    ☐　No, no electric vehicle (exclusive)

29. Are you able to charge these vehicles correctly?
    Filter: if 'No, no electric vehicle' was not chosen in question 28
    ○　Yes
    ○　No

30. Besides your electric vehicle(s), which of the environmentally friendly and low-cost means of transport would you consider to use in the future? Multiple answers possible.
    Filter: if 'No, no electric vehicle' was not chosen in question 28
    ☐　Bike
    ☐　Public transportation
    ☐　Carpooling
    ☐　I am not interested in the above options (exclusive)

31. Which of the following environmentally friendly and low-cost means of transport would you like to use in the future? Multiple answers possible.
    Filter: if 'No, no electric vehicle' was not chosen in question 28
    ☐　Bicycle
    ☐　Public transportation
    ☐　Electric vehicle
    ☐　Carpooling
    ☐　I am not interested in the above options (exclusive)

The following questions are about the apartment you recently moved to.
The following questions are about savings in your apartment.

32. How much of your monthly budget do you spend on energy (gas, electricity, firewood, heating oil, etc.)?
    - ○ Between 5% and 10%
    - ○ Between 10% and 20%
    - ○ Between 20% and 30%
    - ○ More than 30%
    - ○ I don't know

33. Are you experiencing financial difficulties due to the costs of heating your home? Multiple answers possible.
    - ☐ Yes, due to the energy consumption of the heating system being too high
    - ☐ Yes, due to the increasing price of energy
    - ☐ Other, namely: _____
    - ☐ No, I do not experience any financial problems due to heating my home (exclusive)

34. Which of the following measures have you taken to make your home more energy efficient? Multiple answers possible.
    - ☐ Insulation on the inside
    - ☐ Exterior insulation
    - ☐ Attic insulation
    - ☐ Double or triple glazing
    - ☐ Seals (doors, windows...)
    - ☐ I have not taken any of the above measures (exclusive)

35. You indicated that you have not made your home more energy efficient. Can you imagine that you will retrofit your home 2023 or 2024 to save energy?
    Filter: if 'I have not taken any of the above measures' was not chosen in question 34
    - ○ Yes
    - ○ No

35a. Do you think the InterConnect project's devices and services have saved you money?
    - ○ Yes
    - ○ No

Finally, we would like to know more about yourself and your personal situation.

36. What do you identify yourself with?
    - ○ Woman
    - ○ Non-binary
    - ○ Man
    - ○ I prefer to describe it myself: _____

37. What age group do you belong to?
    - ○ Younger than 25
    - ○ 26 to 35
    - ○ 36 to 45

    ○   46 to 55 years
    ○   56 to 65
    ○   Older than 66 years

38. What is your highest level of education completed?
    ○   No completed education
    ○   Primary education to 8th grade
    ○   Secondary education/ high school
    ○   College
    ○   Trade/ technical/ vocational training
    ○   Bachelor's degree
    ○   Master's degree
    ○   Professional degree
    ○   Doctorate degree

39. What is your main activity?
    ○   Craftsman, merchant, or business manager
    ○   Manager or highly skilled profession
    ○   Intermediate profession
    ○   Employee
    ○   Self-employed person (self-employed)
    ○   Farmer
    ○   Retired
    ○   Unemployed
    ○   Other, namely: _____

40. How many hours a week do you work?
    Filter: if 'retired' or 'unemployed' was not chosen in question X
    _____ *(validation: number)*

41. How many days a week are you at home during the day?
    _____ *(validation: number)*

42. How many people live in your household (including yourself)?
    _____ *(validation: number)*

43. What age groups do the people in your household belong to? Please specify the number of people in your household by category.
    ☐   Under 25 years of age: _____
    ☐   25 to 35 years: _____
    ☐   36 to 45 years: _____
    ☐   46 to 55 years: _____
    ☐   Older than 66 years: _____

Thank you very much for your participation. Your responses have been sent.

Interview Protocol

This interview protocol was developed by our InterConnect partners at Yncrea Mediterranee and include 10 questions whose answers are intended to:

- define the lexical field of perceptions of the project by end-users and stakeholders (transnational analysis of marketing messages and communication strategies)
- measure the social, economic, and environmental impacts perceived by these same stakeholders;
- assess the level of social acceptance and trust.

It is important for the study to fulfil its objectives that the document is translated by the person who conducted the interview. It is also important that the interviewer respects as much as possible the terms used by the interviewee.

For your information, the KPI's that we will be able to answer through these interviews are shown in blue at the end of each question.

Information about the interviewee (filled in by interviewer):

Situation (end-user, partner…)	End-user
Age	
Sex	
Level of education	
City of residence	Eindhoven
InterConnect devices available to the interviewee: - Smart washing machine - Smart dryer - Smart dishwasher - Automated air ventilation	

1. Do you think that your participation in the InterConnect project has helped you to improve your knowledge and behavior regarding energy consumption?

2. On a scale of 1 (not at all satisfied) to 10 (fully satisfied), how satisfied are you with the services provided by InterConnect? Please explain your answer.

3. On a scale of 1 (no effort) to 10 (significant effort), how much effort did you make to reduce your energy consumption? If you have made efforts, can you elaborate on them?

4. In the same way, are you planning on making additional efforts to reduce your energy consumption? If yes, can you elaborate on these additional efforts.

5. Since the start of the InterConnect project, have you noticed a decrease in your energy consumption?

If yes, is this due to :
☐ greater attention on your part ;
☐ the InterConnect tools.

6. Did the InterConnect project save you energy? To what extent (significant, moderate, minimal, no extent)?

7. Did you recommend the InterConnect project to your friends, family, and neighbors, encouraging them to participate in the project? If yes, how many people have joined as a result of your recommendation?

8. On a scale of 1 (not at all informed) to 10 (fully informed), how informed do you feel about the InterConnect project? What additional information would you have liked to receive about the InterConnect project (e.g., newsletter, journal, blog...)?

9. Based on this experience, do you think that the technologies you tested should be widely disseminated to improve energy consumption behavior?

10. Do you think InterConnect project can have impacts on the environment? To what extent do you feel engaged in reaching the environmental goals of the InterConnect project?

Appendix C
Summary interview transcripts

Information about interviewees

	Summary
Situation	End-user
Age	Ø 32 years
Sex	2 female 5 male
Level of education	3 bachelor 4 master
Connected to InterConnect	3 not connected 4 connected
Usage of InterConnect	2 usage 2 partly 3 no usage
City of residence	Eindhoven

1. **Do you think that your participation in the InterConnect project has helped you to improve your knowledge and behaviour regarding energy consumption?**
   P1: Yes, both
   P2: No – "At the moment, it makes little difference to me"
   P3: No – "No, not by means of InterConnect. Before connecting to InterConnect, we switched to Tibber, an energy company that provides dynamic pricing insights."
   P4: No – "I live on my own, so I try to live as energy-/cost efficient as possible anyway. I don't know where I can find the effect of InterConnect in this. [...] Ok it could be that I don't know enough about this. I don't use the InterConnect app. I wouldn't know what I could do with it."
   P5: Yes and No - "Knowledge yes, as in we knew a bit about our energy consumption, but because of InterConnect we have delved into it a bit more. Our behaviour has improved sometimes, but not necessarily always. InterConnect unfortunately doesn't work yet."
   P6: Yes – "I was already familiar with dynamic contracts, but now we pay attention more often to when we turn on our devices."
   P7: Yes – "Yes, I think it will help."

2. **On a scale of 1 (not at all satisfied) to 10 (fully satisfied), how satisfied are you with the services provided by InterConnect? Please explain your answer.**
    P1: 9
    P2: 5 – "I don't notice much of it even when I turn the devices on, which is good in itself. It would be nice, however, if you could see the difference in the use between the time chosen from InterConnect and the time you would choose yourself. I don't know now what I could save in the future if I did choose a dynamic contract."
    P3: 8 – "because we have just been connected to InterConnect. I did take a look at the website which looks quite clear."
    P4: 5 – "I am very satisfied with the equipment in the flat, but I do not use InterConnect"
    P5: 1-2 – "not very satisfied. Efforts were made to help us, but the communication was very poor."
    P6: 8 – "Overall, we are satisfied, but InterConnect has had some problems starting up."
    P7: 5 – "I can't say much about it because I don't use InterConnect yet so I'm impartial at the moment."

3. **On a scale of 1 (no effort) to 10 (significant effort), how much effort did you make to reduce your energy consumption? If you have made efforts, can you elaborate on them?**
    P1: 7 – "I am still quite reactive so far: I notice that only when the seasons change (e.g. it's getting colder now), I think about how to deal with it in my household (e.g. more insulation, etc.)."
    P2: 6 – "I run my own server with a home assistant linked to the InterConnect devices (mainly lighting and sensors). The InterConnect app is quite annoying: The app is very slow to open because it opens via the cloud. The home assistant I installed is better because it is much more responsive. [...] I would prefer to be able to set the times on the dishwasher itself."
    P3: 9 – "because we have Tibber (energy retailer) and are doing a lot in regard to our energy consumption."
    P4: 7 – "I try to keep my heating below 20 anyway..."
    P5: 7-8 – "We do our best, but sometimes it's just easier to ignore it."
    P6: 8 – "I think we did get serious about it."
    P7: 3 – "Honestly, my partner and I are not very engaged at the moment. We would like to, but it requires a more active approach."

4. **In the same way, are you planning on making additional efforts to reduce your energy consumption? If yes, can you elaborate on these additional efforts.**
    P1: Yes - "if I see effect"
    P2: Yes - "Yes at the moment it is mostly lighting, but in the future I do want to use the smart features."
    P3: Yes – "Yes, I am willing, but we are already maxed out."
    P4: Yes – "When I get started with the InterConnect system and if that has an effect, I will start using it more. I have to experience that first."
    P5: No
    P6: No – "I don't think there are a lot of additional efforts to be done, [...]"
    P7: Yes – "We have an appointment scheduled for 11 December to be connected to InterConnect. [...] So I can see us making more of an effort in the future."

5. **Since the start of the InterConnect project, have you noticed a decrease in your energy consumption?**
P1: "I haven't noticed any decline in costs, but I have noticed that costs remain stable"
P2: "No, not really."
P3: "I think the correlation between using the smart functionality (InterConnect) and a drop in energy consumption should normally be obvious, but not in our case. The gain achieved is marginal. It's not going to add 10%."
P4: "What is the reference? I think my energy consumption is quite reasonable (the average household uses 150kWh, I'm at between 120 and 130kWh) and whether that has to do with InterConnect I don't know."
P5: No – "I don't have a comparison with before we moved into this building either. Before this, we lived in separate apartments so it's hard to compare."
P6: "I have no insights into that."
P7: "The two of us then often use as much as an average 1-person household. [...] . I am curious to see whether we reduce our energy consumption even further when we will be connected to InterConnect in the near future – would be nice to be able to gain that insight."

If yes, is this due to:
a)　greater attention on your part ;
b)　the InterConnect tools.

P1: Both
P2: Not applicable
P3: Greater attention on our part
P4: Not applicable
P5: Not applicable
P6: Not applicable
P7: Not applicable

6. **Did the InterConnect project save you energy? To what extent (significant, moderate, minimal, no)?**
P1: No – "It did not really save me energy, but it has remained stable from the start. InterConnect taught me from the beginning how to handle my energy consumption properly."
P2: No – "Not significant."
P3: Minimal
P4: Minimal
P5: Minimal
P6: Moderate – "but this is an assessment because I have no insight."
P7: Minimal or no

7. **Did you recommend the InterConnect project to your friends, family, and neighbors, encouraging them to participate in the project? If yes, how many people have joined as a result of your recommendation?**
P1: Yes – "Not that I talk about it daily, but when it comes up naturally."
P2: "I did not recommend it, but I did talk about it. When someone visits, I talk about the system but also its flaws."
P3: "Not recommended, but I did talk about this. [...] So taking Tibber out of the equation, I would recommend InterConnect."
P4: "I don't know enough about the InterConnect project itself, but the whole flat I recommended."

P5: "Not always in the positive sense, but rather that we have an dynamic contract and that it can really be more beneficial to turn on the devices at certain times. We did talk about that with family and friends."
P6: "Not so much about InterConnect, because it is linked to our building, but the use of dynamic contracts. This is what I am talking to friends and family about."
P7: Yes – "Coincidentally last week I talked about InterConnect with a colleague of mine, so yes. [...] So I happened to talk about it with a colleague last week, and maybe I talked about it once with my parents."

8. **On a scale of 1 (not at all informed) to 10 (fully informed), how informed do you feel about the InterConnect project? What additional information would you have liked to receive about the InterConnect project (e.g., newsletter, journal, blog…)?**
P1: 9 – "Personal contact has been the case in this matter and I found that special because I haven't experienced it in such a way before"
P2: 9
P3: 8
P4: 4 – "There have been some informative moments, but apparently I'm not up to speed on everything. This could also be me. I don't think I need explanations, but some kind of reminder that there are actions that can and should be taken."
P5: 8-9 – "We then went to the information evening last year."
P6: 8 – "well informed. When InterConnect wasn't working properly due to technical issues, we could have been better informed about what exactly the status was and when we could expect a solution. The communication could have been better."
P7: 8 – "There is no additional information needed at the moment, maybe later when it's up and running."

9. **Based on this experience, do you think that the technologies you tested should be widely disseminated to improve energy consumption behaviour?**
P1: Yes – "Personal contact has been the case in this matter and I found that special because I haven't experienced it in such a way before"
P2: Yes – "Yes I think it is useful."
P3: Yes – "100%, yes I think so"
P4: "I can't comment on that because I haven't used this yet."
P5: Yes – "Yes, provided it all works."
P6: Yes – "Yes I think so."
P7: Yes – "Yes why not. It takes little to no extra effort."

10. **Do you think InterConnect project can have impacts on the environment? To what extent do you feel engaged in reaching the environmental goals of the InterConnect project?**
P1: Yes – "I think it can definitely have an impact on the environment."
P2: "I don't feel very involved, but I think it can have an impact."
P3: Yes – "Yes, I do think it has an impact on the environment. Yes, I feel committed to achieving environmental goals."
P4: "I am in a two-fold position. In principle, I am for environment and climate, but I don't think this is THE solution. I think it is a good alternative to what we have now, but whether it is widely applicable (and affordable) I do not know. Besides, there are other things that can have an effect on the environment. Certainly this is a good project, despite my apparent ignorance of it. I am trying to participate, but I don't think I am very much involved."
P5: Yes – "I think it could have a real impact on a large scale. [...] Yes I feel very involved."

P6: Yes – "Yes, I think it definitely contributes and yes, I feel involved."
P7: Yes – "From my own perspective, I would say yes, it contributes to improving/ mitigating the environmental problem. So, yes I do expect it to have an impact. I definitely feel involved."

Suggestions

1. **More information on impact**
    "I would like to be more informed about my impact on environmental goals - also about the savings and impact of the whole apartment complex ('you have saved X, this is the biggest savings you can still achieve'). This would encourage me and others to do even more: 'If you do this and this, you can save this and that'. But also, 'How does it compare at Strijp S with all the flats?' Perhaps another newsletter about what can be achieved with InterConnect. "Did you know that X€ can be saved on a monthly/annual basis?"

2. **A screen in the entrance hall**
    "No, there is no display screen, but seems like an ideal means of displaying all the information. However, there was vandalism in the apartment complex (dirt and alcohol bottles at the lift and entrance) so surveillance would have to be added or the screen should be placed behind a glass."

3. **Difference in cost between usage of InterConnect and own chosen time**
    "It would be nice, however, if you could see the difference in the use between the time chosen from InterConnect and the time you would choose yourself."
    "It would be nice to have more insight into how much you actually save, though. A comparison between the delayed start setting and the actual moment one chooses to turn on the appliance."

4. **More information on (and choice in) percentage of green energy**
    "Also, there is too little information about the percentage of green energy and grey energy at the moment I use the appliances. It would be nice to be able to choose in your account between either as much green energy as possible or just price-orientation."

5. **Power outlet to manually add devices to InterConnect system**
    In terms of power management, I miss some important functions, such as controlling an air conditioner and other power-hungry appliances. It would be nice if InterConnect included some kind of power outlet by which you could still add these appliances.

6. **Connecting a home battery to InterConnect**
    "Another feature I would like is being able to connect a home battery to InterConnect. If you do that, then you can fully schedule your power usage in the off-peak times on the lower off-peak tariff. To connect a home battery to InterConnect doesn't seem like a big technical challenge to me, but in terms of functionality for the user, you would really add value. Then you really start saving energy significantly."

7. **Connecting electric cars to InterConnect**
    "[...] I would like a solution for my electric car. In terms of opportunity and case study, our apartment complex of 100 tenants is interesting because around 10% of the tenant have an electric car. So if you already have serious energy savers, it would be an interesting business case if the electric cars could also be charged in the garage."

Complaints:

1. **Loxone app is very slow**
   "The InterConnect app is quite annoying: The app is very slow to open because it opens via the cloud. [...] The app is slow, and it takes extra steps to use the smart devices."
   "The Loxone app is not the most convenient platform because the app is really slow. [...] About the Loxone app: it takes several seconds until I am logged in – 10 seconds at least and I am not even exaggerating"

2. **Buttons on the devices would be easier**
   "With the dishwasher, it would be easier if I could set a fixed time. Now I have to go to the app first to set the times there. I would prefer to be able to set the times on the dishwasher itself."
   "Our lamps in the kitchen and living room are linked, so if e.g. you want to switch on the lamp in the living room but not in the kitchen, you can't do this via the button but only via the app. If you then have to wait 10 seconds every time until you're in the app instead of pressing a button, it's just annoying."

3. **Sometimes information overload via mail**
   "I think they provide solid and adequate information on the most important things, but it would be good to realise that it could come across as an information overload."

4. **Too many apps**
   "It feels like it's very complicated now – maybe because it doesn't work at the moment, but also because different devices need to be connected to different apps. So off the top of my head, you need a total of 4 apps."

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