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The reduction of auxiliary energy consumption at manufactural processes, by means of influencing machine-operator behaviour through the use of factual and social feedback

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The reduction of auxiliary energy consumption at manufactural processes, by means of influencing machine-operator behaviour through the use of factual and social feedback

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PREFACE

This master thesis was written at the end of my Master of Science study: Human Technology Interaction at the Eindhoven University of Technology. When I look back at my studies, I believe I have learned a lot, in the technological field as well as in the field of psychology. Not only professionally, but also at a personal level. Therefore I would like to give thanks to my teachers and supervisors from the Eindhoven University of Technology; Prof. Dr. Cees Midden and Dr. Jaap Ham, for their invaluable input towards my research project, from start to finish. I would also like to thank my family and friends who have supported me during this wonderful study, but also for the support they have given me all of my life.

For the wonderful time in Ireland, I would like to thank Frank Doyle and his many honeybees for giving me not only an educative time in Éire, but also an enjoyable one. Likewise, I would like to thank my Irish supervisor of the Limerick Institute of Technology; the well-educated 'Energy Doctor' Dr. John Cosgrove, for his professional input and for making me feel at home in Ireland. Furthermore, I also want to thank my colleague and outstanding hurling player, Paudie O'Brien, for his precious support and for the time he took to reply to my many queries. I also would like to thank Mr. Mike O'Neill for his cooperation and his admittance for deploying my research studies at Takumi Precision Engineering Ltd., many thanks go out to his colleagues and invaluable participants of this research.

Last, but not least in the slightest, I would like to give thanks to my wonderful girlfriend Linda for her unconditional love, even when I was fatigued and disgruntled by the amount of work and nearly not as nice as I could have been. Your unwavering support is very much cherished; just like your bright and sunny comments are.

Thank you all for your guidance and for allowing me to write this thesis, for granting me to conduct the experiment, and for giving me a memorable time in Ireland, so I may look forward to coming back any time soon.

Go raibh maith agat Éire!

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ABSTRACT

Energy efficiency is an important aspect in reducing carbon emissions. Nowadays, one of the main objectives of the European Commission is to reduce CO2 emission. In all kinds of industry, where energy consumption and carbon emissions are high, being energy efficient is considered essential.

Previous studies have proven the importance of adding feedback, as a means of changing behaviour for the benefit of energy consumption reduction. The providing of social feedback has revealed better results than factual feedback by itself. However, these previous studies were all achieved in fully controlled laboratory settings.

Our study has investigated the importance of adding factual ánd social feedback, in order to reduce energy consumption, of manufactural processes in an industrial environment, rather than trying to reduce energy consumption in a controlled laboratory environment. In this study, a survey has been distributed to industrial factory personnel in order to create a stimulus material for factual and social feedback in this research experiment. In our experiment, machine operators have received factual feedback through a power gauge, which has been displayed on a screen next to their work environment, or they have received social feedback through emoticons on their screens. The provided feedback is based on the amount of energy consumption by the machine during production time and during machine idle time (the time period between productions). Positive feedback is displayed whenever the operator turns off the machine after producing a part, and negative feedback is provided when the operator lets the machine run idle after a production.

Research results have shown that the machine operator's behaviour has been positively adjusted by the provided feedback. Moreover, social feedback even has a stronger persuasive effect than factual feedback. The machine's total energy consumption had significantly been reduced, whenever the operator had received any kind of feedback. Notably, when the operator is provided with social feedback, the total energy consumption is reduced even more (a 5.1% energy reduction), when the operator receives factual feedback (a 2.8% energy reduction).

This study shows that providing participants with feedback leads to a significant increase in production efficiency. By providing feedback to the workers, this factory is able to produce thirteen products in the same amount of time it would normally (without feedback) take to produce twelve products.

Conclusively, our research study proves that energy consumption can be significantly reduced by providing workers with feedback (on their screen for example), especially social feedback. These modus operands can diminish carbon emissions and energy costs. Our research confirms the importance of adding (social) feedback to industrial manufactural processes in order to reduce energy consumption.

1. Introduction

Creating a resource efficient and a low-carbon (low-CO2 emitting) economy is one of the most important issues nowadays. Therefore, the European Commission has been promoting energy efficiency as a central flagship initiative (European Commission, 2010). One professional sector, in which energy efficiency is such an important issue, is in industry. Industrial manufacturing processes generate a significant environmental impact through their high amount of energy consumption. Hence, enhancing energy efficiency can prove to be of great importance in reducing resource depletion and even carbon emission (Schmid, 2004). As prerequisites for greenhouse gasses reduction (GHG) are likely to further increase with imperatives from the European Commission, it is to be expected that the insistence increases on industry, in order to reduce their energy consumption footprint.

For any industrial company, it can be challenging to focus on, and to invest in finding ways to increase their energy efficiency. Christoffersen (2006) and Thollander (2010) have recognized that only a small amount of companies actually focus on their energy management. There seem to be some barriers withholding them from the implementing energy efficiency measures. Main barriers for not managing energy are; a primary focus on production, lack of time, having other priorities, technical risks, lack of capital, and lack of knowledge on how to improve their energy efficiency (Hasanbeigi, Menke & Du Pont, 2010; Shipley & Elliott, 2001; Thollander, 2012). Despite the many hurdles a company has to overcome in order to make industrial processes gradually more energy efficient, these implementations are still essential in reducing carbon emission.

Particularly in energy intensive parts of industry, e.g. the manufactural environments, research indicates that there is an important unrealized potential to further reduce energy consumption by 15–25%, where 47% of this 15–25% range can be achieved by improved energy management and behavioural changes (Granade, et al., 2009; Jollands, Tanaka, Gasc, & Wescott, 2009). This has been confirmed in a survey by Belgian and Dutch industry that showed that behavioural change can contribute to savings of 5-15% of an industrial site's energy consumption. (DNV GL, 2011; Wising, et al., 2014). This indicates that energy management and behavioural change are substantial factors in reducing energy in industrial manufactural environments.

In order to allow improved energy effectiveness, industry must first understand its own energy demand, consumption, and how these two are managed, particularly in the manufactural environment (Mustafaraj, 2015). After having investigated a factory's energy flow, industry can further focus on changing their employee's behaviour patterns, towards a more energy efficient behaviour (Wising, et al., 2014).

A tool called a Sankey diagram can be used, to identify and illustrate the most significant energy users (SEU's) in a factory environment. This tool provides a quick and clear overview of energy distribution of the machines and of the processes within a factory and it helps to identify the largest energy user. The largest significant energy user (SEU) can be formulated as the highest priority to begin their saving on energy with. Hence, the highest objective in energy saving is to single out the most energy demanding manufactural processes (Cosgrove, 2011). Figure 1.1 illustrates a Sankey Diagram, on how energy is distributed within a prototype industrial production facility (Cosgrove, 2011). First, this figure illustrates how the primary incoming energy is split into Direct Energy (which powers the manufactural processes) and Indirect Energy (which powers the factory's facilities, such as Heating, Ventilation and Air Conditioning (HVAC) and Lighting). The manufactural environment's direct energy can be further split into two major energy streams; value-added energy and auxiliary energy. Value added energy is the energy needed for the manufactural process part when the product is made. The auxiliary energy is defined as the energy consumed by supporting activities and auxiliary equipment within such a manufactural process, as shown in Figure 1.1.

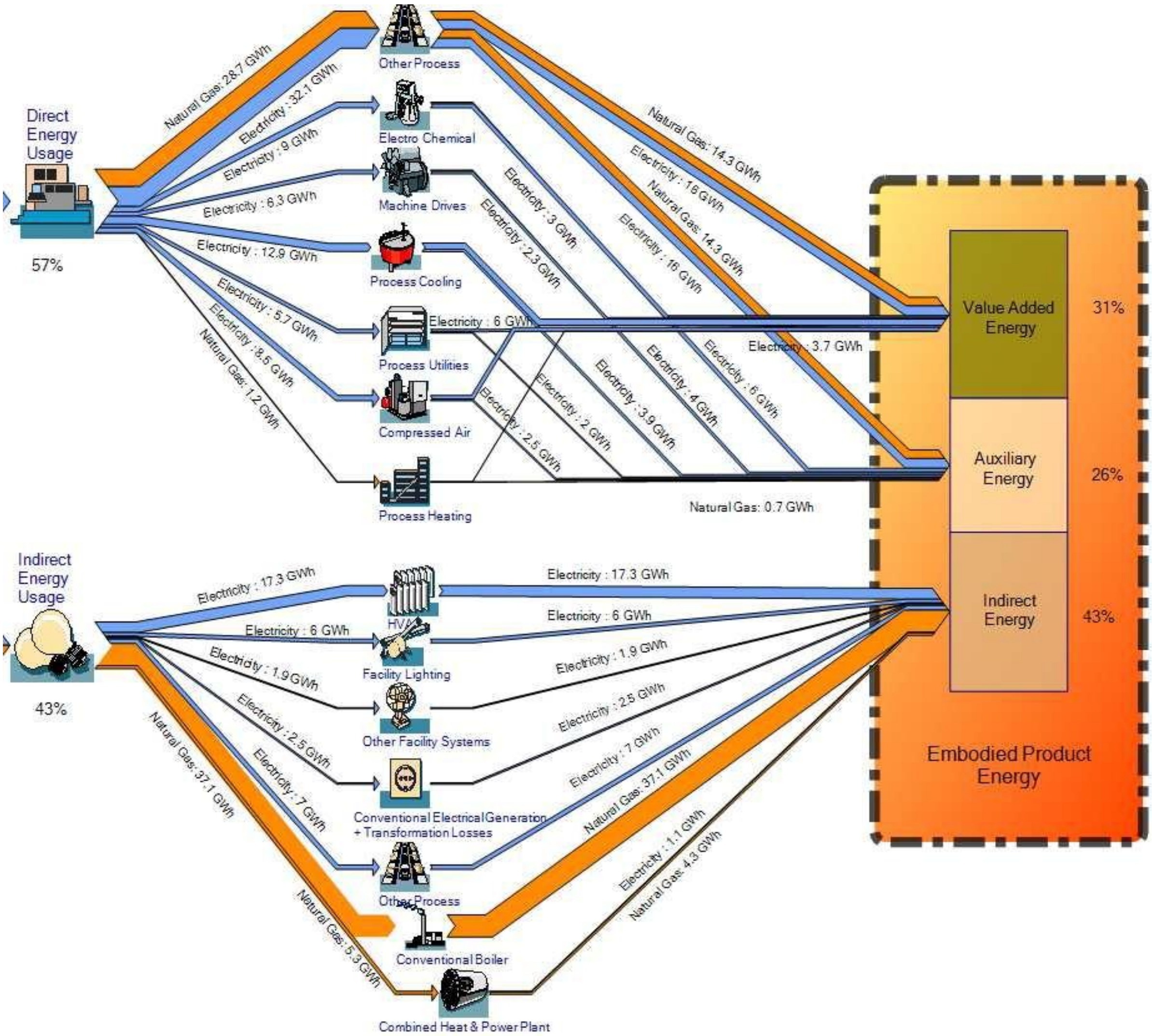


Figure 1.1. Sankey diagram illustrating the flow of energy per significant energy user (SEU) and categorised into Value Added, Auxiliary and Indirect Energy. (Adapted from Cosgrove, 2011).

In this examplatory Sankey diagram, the Cooling Processes can be identified as the largest energy user in the manufacturing environment's direct energy use. Therefore, this process should be addressed as soon as possible, as a means on how to save energy.

In general, direct energy user profiles can be subdivided into 'Value Added Energy' (variable energy consumption) and 'Auxiliary Energy' (fixed energy consumption) profiles (Gutowski, 2006). The 'Value Added Energy', or variable energy consumption, of, for example a production machine, incorporates the required electrical energy used for tool handling, positioning, and the actual operation (e.g. milling, cutting, turning). The 'Auxiliary Energy', or fixed energy consumption, incorporates the energy required to aid the machine at its processes (e.g. machine components such as control units, tool changers, pumps or fans). These processes enable an operating state and are always active, regardless of product manufacturing or not. So, depending on the specific type and configuration of the machine and its utilization, the auxiliary (fixed) energy consumption, which is not a directly value-adding energy, can take up a major share of the total energy consumption (Herrmann & Thiede, 2009).

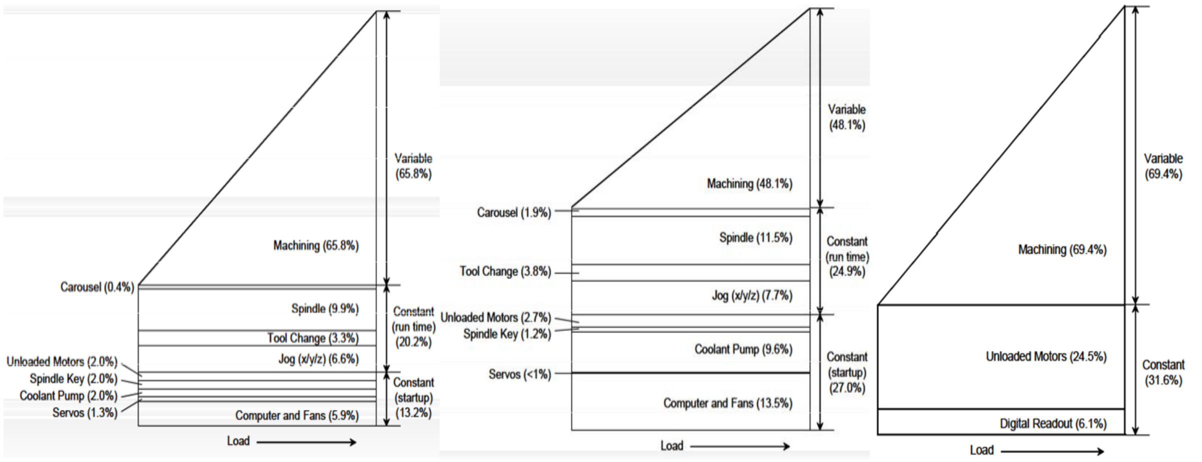
In order to cut back on 'Value Added Energy', machines might be made more energy efficient, or could be replaced with a more energy efficient one. However, when not considering machine upgrading or machine replacement, energy can be saved by reducing 'Auxiliary Energy'. 'Auxiliary Energy' is needed when a product is being manufactured, but is excessive when the machine is idle and when the machine is waiting for a product to be manufactured. Generally speaking, machines are being held online twenty-four-seven, 365 days per year. Simply by modifying the machine operators' action to turn off the machines when they are running idle, a large amount of energy will be cut back. 'Auxiliary Energy' is the one part of a machine's energy consumption, which can be seen to be the most lucrative part on energy saving (Cosgrove, 2011), and therefore these energy flows should have to be identified in a factory through the use of a Sankey diagram as illustrated in Figure 1.1). So, when the machines turn idle, the 'Value Added Energy' consumption can be returned to zero, but the 'Auxiliary Energy' is still passively squandering energy.

1.1 Savings on auxiliary energy

In a manufactural environment, in addition to supplying energy to the machine tool tip, where the product is manufactured or can be reformed, energy must also be provided for power auxiliary equipment; such as generating a vacuum for sand casting, the pumping of a coolant for machinery, work piece handling equipment, tool changers, computers and machine lubrication systems (Seow, 2011). In some cases, for example, when operating a cutting machine, the energy requirements of the auxiliary equipment might even exceed the actual primary (e.g. cutting) requirements by far. The energy consumption is therefore not largely determined by the energy needed for the primary operation, but it is dominated by basic power consuming components (Auxiliary Energy). This energy is mostly constant and it does not depend on whether a part is being produced.

Saving on 'Auxiliary Energy' can be beneficial when the amount of energy that is saved, is large enough when compared to the total amount of energy consumed by any machine. Dahmus and Gutowski (2004) have identified the percentage of 'Auxiliary Energy' in the total amount of energy that is consumed by machines in a manufacturing company. They conducted a study on three different milling machines with different auxiliary equipment capacities and have discovered that, depending on the machine's model, thirty-two to fifty-two percent of the energy consumed, is constant regardless of the load (See Figure 1.2).

In other words, when there is no product available for the machine to work on (the machine's idle state), the machines still consumes a substantial amount of energy. This is confirmed by a similar study on a 5-axis milling machine, where Devoldere, et al. (2007) have found that sixty-five percent of operation time was non-productive, and this non-productive state ('Auxiliary Energy' state) accounted for up to forty-seven percent of the total energy consumption.



1998 Bridgeport automated milling machine with 5.8 kW spindle motor

1988 Cincinnati Milacron automated milling machine with a 6.0 kW spindle motor

1985 Bridgeport manual milling machine with a 2.1 kW spindle motor

Figure 1.2. Energy usage report, for various automated milling machines. (Adapted from Dahmus and Gutowski, 2004)

The results of the previous studies from Dahmus and Gutowski (2004) and Devoldere (2007) have confirmed that a machine in an idle state consumes substantial amounts of energy. Devoldere, et al. (2007) indicate that about a third of the total amount of energy, that a machine consumes, is wasted annually. Therefore, significant amounts of energy savings can be achieved by turning off a machine when it is in its idle state; when the machine is waiting for the next product to arrive, so it can be further manufactured.

This unnecessarily wasted energy by machines that are waiting for the next product to arrive, might best be saved by simply turning off the machine when idle, but unfortunately is not applicable to every machine. An oven, for example, should not be turned off for even short amounts of time, as these kinds of machines are slow to restart and it can cost a lot of energy for these machines to build up their required temperature again. Some other machines, such as precision milling machines, might have trouble with alignment when they are restarting. This is why careful decision making, is important to identify which machine can or cannot be turned off frequently, in order to save energy. Furthermore, turning off idle machines is only possible when the machine operators, who are competent and who are qualified to turn off machines, have the authorisation and the required expertise in what situation a machine could be turned off. By carefully selecting the machines in order to reduce energy, and by providing instructions to the operators in which situation the machine should be turned off, the machine's annual energy consumption can be reduced significantly.

1.2 Factual and social feedback to influence behaviour

Many strategies, aimed at behavioural change have already been analysed, with each strategy focusing on a different set of behavioural determinants (Gardner & Stern, 2002; Geller, 2002; Geller et al., 1982). Geller et al. (1982) have made a distinction between antecedent and consecutive strategies for successful behavioural change. Consequence strategies are aimed at changing the consequences following behaviour. Feedback, penalties and rewards, have all been proven to be effective in energy related behavioural changes (Geller et al., 1982). According to Arroyo (2005), providing feedback is an effective way to change someone's behaviour in energy related tasks, and this feedback can naturally be provided through various types of technology. Fogg (2009b) argued that the best way to make technology persuasive is to make something small, simple and understandable. Therefore, in this research, it is understood that feedback which is given through easily understandable technology, can be a promising method in order to change behaviour needed for energy reducing tasks.

To make the task easily understandable, the participants should be given clear instructions about what to do during the task.

In order to save energy, machines should ideally be turned off right after each manufacturing process, when power (in particular direct energy) is not needed for production. Providing information about when to turn off the machine is essential. The sooner the operator receives a signal that the product is finished, the sooner the operator will be able to turn off the machine.

Therefore, more energy will be saved during the whole manufactural process. One way to go about this, is to provide an energy indicator, which signals when the machine is finished with the task and which thus signals when the machine is running idle. For example, when the machine's energy consumption steeps below a given power consumption level (threshold), the machine will be identified as idle, and an indication signal is activated.

While indicators for the consumption of energy are suited for demonstrating the current amount of energy consumption by the machine, Van Houwelingen and Van Raaij (1989) have pointed out that this kind of information alone is not a very effective strategy for reducing energy consumption. Information has proven to be more effective when used in conjunction with other interventions.

Abrahamse, et al. (2005) conducted a literature review on the effectiveness of interventions steered towards encouraging households to reduce their energy consumption. In their study, several strategies were investigated and compared to effectiveness. Accordingly, they have suggested that energy indicators (or factual feedback) are important in order to promote awareness knowledge. However, when it comes to altering someone's behaviour (e.g., turning off a machine), it is better to use a combination of both factual and social feedback, than to provide factual information on its own (Van Houwelingen & Van Raaij, 1989). Factual feedback can be given to employees by displaying a digital sign with numeric kWh information, whereas social feedback can be given as positive or negative facial expressions and utterances shown on a computer screen (Midden, & Ham, 2008). Correspondingly, research by Ham and Midden (2008, 2009, 2014) has suggested that using Social Feedback and using Factual Feedback, is beneficial in altering one's energy consuming behaviour.

Feedback given to participants can be provided through inter-human communication, but it can also be given through the use of an agent. An agent can be defined as an entity, that identifies information through sensors and acts upon this newly received information (Yonghui, 2013). Ham and Midden (2014) have conducted a research study where the persuasive effect of Social Feedback given by a robotic agent, the iCat, was explored. The Social Feedback was being compared to the, more widely used, Factual Feedback. Throughout this investigation, results have indicated that Social Feedback has stronger persuasive effects than Factual Feedback has. It seems to be that Social Feedback is more akin to human intercommunication than Factual Feedback is (Reeves and Nass, 1997).

Persuasive technology can be outlines as a technology that is aimed at altering the behavior of the users through social persuasion, social influence, but not through the use of force. (Fogg, 2002) These persuasive technologies encompass desktop computers, Internet services, video games, and mobile devices (Oinas-Kukkonen, et al., 2008), and they rely on results, theories, and methods of experimental psychology, rhetoric (Bogost, 2007), and human-computer interaction.

Research carried out by McCalley and Midden (2002) suggest that Persuasive Technology that provides intensive forms of feedback can be effective in enhancing energy efficiency. McCalley and Midden (2002) have conducted a study starring a washing machine. Through the adding of an energy meter, that provided factual feedback in the form of a kWh user programming choice, an eighteen percent energy reduction had been achieved in both laboratory studies, as well as a field research.

Laboratory research has provided better insight in the separate and the combined effect of interventions (McCalley & Midden, 2002). For instance, the study of Ham and Midden (2014) has given back promising results to alter behaviour, accountable for energy consumption. However, this study has been performed in a controlled laboratory setting. As a result, these findings are still to be tested in a non-controlled environment, such as an industrial production facility. The Factors in the Behaviour Model (FBM) as defined by Fogg (2009a) illustrate three important principal factors, that can be used in order to alter a person's behaviour. These factors are; motivation, ability, and triggers. This FBM model implies that in order for a preferred behaviour to happen, a person must have sufficient motivation, sufficient ability, and a person must have an effective trigger. When one would want to generalise results from a laboratory study, these three parameters should match reality as closely as possible. In the controlled laboratory study of Ham and Midden (2014), the participants were not company employees, but they were Master students from a technical university. Remarkably, participants who were involved in the laboratory studies of Abrahamse (2005) tended to have a higher than average income and a higher than average education level and they were inclined to be highly motivated. Therefore, making generalisations based on these laboratory studies can be rather difficult. It still remains unclear whether the advantage of social feedback that contributes to saving energy will also remain valid in a less controlled environment, that might have access to less educated and less motivated personnel as their participants. On that account, we have completed our research in an industrial manufactural facility, with its own industrial machine operators in order to replicate reality as close as possible.

1.3 Goal

Based on previous chapters, the current study will try to add valuable insights into the investigation of the effectiveness of factual versus social feedback, in regard to the reduction of Auxiliary Energy consumption in a manufactural environment. As a result, the following research question is formulated and has been investigated throughout the length of this study:

What is the effect of factual versus social feedback given to machine operators, on Auxiliary Energy consumption in a manufactural environment?

In order to answer this primary research question, the following secondary questions have to be answered first:

- Question 1: What kind of factual feedback should be given to machine operators in industry to save on the consumption of energy?
- Question 2: What kind of social feedback should be given to machine operators in industry to save on the consumption of energy?

Based on the literature review in the previous chapters and in order to answer these primary and secondary questions, three hypotheses have been formulated, analysed, and have been investigated throughout the remainder of this document.

1.4 Hypotheses

As discussed in previous chapters, the effect of feedback on behaviour is well recognised in various studies. Expectations in this study are that, by using a different kind of environment and a different kind of participants (compared to previous laboratory study examples), feedback results will be positive in regards to energy efficient behaviour. Therefore, the first hypothesis has been defined as:

H1: Factual & Social Behaviour will make the participants behave in a more energy efficient way.

Expectations are, that social feedback provides the strongest persuasive power for someone to change one's behaviour, as discussed in chapter 1.2. Responsively, the second hypothesis has been defined as:

H2: Participants who receive social feedback will be able to shorten the machine's idle time more often than participants who receive factual feedback.

As shown in section 1.1, the amount of energy which can be saved can be within the bandwidth of 5-15%. Based on these prospects, we expect to save at least 5% of the total energy consumption per product produced of the target manufacturing machine of the production facility due to the provided feedback. Expectations are that the feedback will affect the energy efficient behaviour in a positive way, when compared to conditions without any feedback. Therefore, the third and last hypothesis is formulated as:

H3: Less energy will be consumed by the machines when feedback is provided to the machine operators, than when operators receive no feedback at all.

A five percent reduction in energy consumption will result in a saving of approximately €80 on the target single machine's monthly energy bill, or respectively €960 on an annual basis. If this concept could be applied to the whole factory's machine park of the target precision engineering company (which contains 5 similar types of machines), savings could be further enlarged to a €400 monthly, or a €4,800 annually. Potentially, if the top end of the bandwidth of fifteen percent savings is taken into account, then these results can be stretched to a €1,200 monthly or to a €14,400 annually. Additionally, because this research manufacturing company is only a Small-to-Medium Enterprise (SME), savings will be significantly higher when this concept is applied to a medium or large manufacturing company.

1.5 Method

This investigation will be conducted in a precision engineering, medical orthopaedics manufacturing facility based in Limerick, Ireland. Two machines will be monitored in a manufactural environment during the experiment. The provided feedback will be displayed to the machine operators through a screen. This screen is set-up close to, and in sight of the machine operator.

In order to accomplish maximum cooperation and validity with the participants, the study will be set up threefold: Firstly, because the participants' engagement is very important, there will be a pre-experiment questionnaire held concerning the preferences, with regards to this experiment, of the factory floor employees. During this questionnaire nine different factual and social feedback types will be presented. Results will be able to indicate the most preferred social and factual feedback type, that is to be used in the energy engagement experiment later on.

Secondly, an energy engagement experiment with the selected feedback from study 1 on energy use per produced product, will be conducted. Throughout this experiment, the influences of social and factual feedback on the energy efficient behaviour, that is displayed by the machine operators, will be investigated. Our hypotheses will be tested through the use of a within-participants Mixed Model Design in order to test the influence of factual and social feedback on energy efficient behaviour.

Lastly, a post-experiment questionnaire will be conducted to gain further insight into the participants' thoughts and ideas for future development and implementation of the feedback method in this manufactural environment. With these results combined, a thorough advice can be formed on which kind of feedback and why it should be implemented in the future as a means to efficiently reduce energy consumption.

The applied methodology per study is explained in more detail in their corresponding chapter later on in this report.

1.6 Contents of the thesis

As just discussed in chapter 1.5, this research consists of the following three phases:

There will be a pre-experiment questionnaire about the opinion and preferences of factory floor employees, this which will be explored during the course of chapter 2.

In chapter 3, the second and also the main part of this research will be discussed; this consists of the energy engagement experiment within the manufacturing environment, that is based on factual and social feedback, given to machine operators.
The third and final part of the study, the post-experiment questionnaire, will be examined in chapter 4, where the machine operators' experiences of the energy engagement research will be evaluated.
Conclusively, this whole research study will be reviewed in the general discussion chapter 5, where the results of the experiment will be disclosed, the initially formed research question and hypotheses will be answered, and further recommendations for future research and future implementation of the feedback method will be enclosed.

2. Study I: Pre-experiment survey

2.1 Introduction

Making sure that the workforce is engaged in energy efficient operations is one of the key principles of energy reduction in industry (NRC, 2015). Consequently, the interest and in addition providing the opportunity for machine operators to share their opinions, is an important factor. However, it can be a challenge to acquire the necessary cooperation from employees for a behavioural study on energy efficiency in a manufacturing company, because the employee's main focus is to be productive rather than to be energy efficient.

Gaining acceptance of the used feedback materials is of great importance. Meschtscherjakov, Wilfinger, Scherndl, & Tscheligi (2009) have contended that a lack of acceptance will lead to a rejection of the technology by its own users. For this reason, this study will conclude which type of social and factual feedback would be considered most acceptable for the subsequent research experiment (study II).

An explorative survey has therefore been conducted in order to develop suitable factual and social feedback stimulus material. Additionally, this survey explores the participants' demographics, background, and their opinions on different types of feedback. This survey will indicate their preferences and their acceptance of feedback being given during their work.

2.2 Method

2.2.1 Participants

Seventeen employees (aged 24-52, *M* = 38.65, *SD* = 9.39) at a precision engineering company, of which 16 were male and of which 1 was female, have completed the survey. Eleven out of 17 employees work in the manufactural environment of the company. Six out of 11 manufactural environment employees hold on a leadership function (2 engineers, 3 production team leaders and one operations manager); the other 5 are operators and analysts.

Although the gender distribution for this study deviates highly towards a male majority, in manufactural environments it is quite typical to have a high majority of the male sex. For example, Taiwo, et al. (2008) have illustrated in a study (about sex differences regarding injury patterns amongst workers in heavy manufacturing), that it is commonplace to have a 9:1 male-female ratio in a manufactural environment. A highly anomalous male-female ratio is thus not seen as an obstacle for further research studies, because it truly reflects the nature of a work environment as realistically as possible.

2.2.2 Materials

A survey was distributed among the staff, in order to investigate the employees’ awareness, abilities, willingness, and their experiment feedback preferences.

Apart from general demographics, the survey contained questions, for instance; whether they are aware that a machine, when it is running idle, still consumes energy and that it can be turned off. Furthermore, it contained questions on their awareness, and their willingness, to turn off a machine at a given time and questions were asked on whether the employees had the authority to do so. The survey, incorporating all these questions, is presented in appendix A.

At the same time, nine different forms of feedback, of which three were social feedback and of which six were factual feedback, where presented as illustrated below in Figure 2.1. Social feedback types that were used here were the Emoticon, Male- and Female Avatars, and the rest were factual types of feedback. Participants were asked to rank them according to personal preference and to rank them according to their predicted effect that the feedback might have on reducing the machine’s energy consumption.

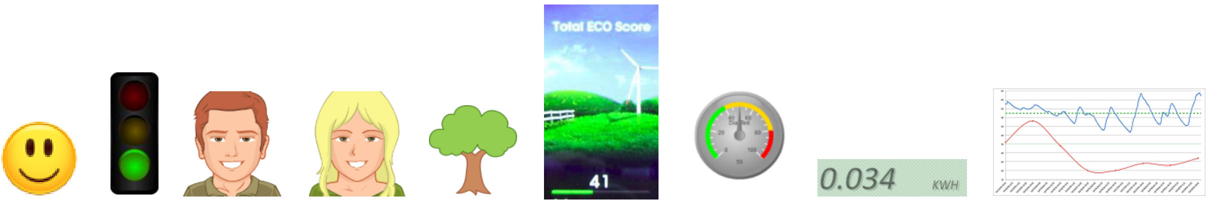


Figure 2.1. Feedback figures. From left to right: Emoticon, Traffic light, Male Avatar, Female Avatar, Growing Trees, Eco Score, Power Gauge, Digital indicator, Graph. See Appendix A for a more detailed explanation on each form of feedback.

2.2.3 Procedure

During an in-house energy event held by the precision engineering manufacturing company, the upcoming experiment (study II) has been demonstrated to their factory employees. During this presentation, our survey was distributed to employees, who were interested in participating in the experiment.

After agreeing to participate, these cooperative participants were kindly asked to complete the questionnaire and to return it after. The first part of the questionnaire had dealt with the participant’s energy awareness, their energy consumption knowledge, and their willingness to save on energy. The second section of the survey involved selecting stimuli material for the prospective research experiment.

The questionnaire itself is included in Appendix A and the results are displayed in Appendix B.

2.3 Results and Discussion

The main purpose of this research study was to develop factual and social stimulus material for the successive research experiment (study II), by the means of a survey.

In general, the participants have sincerely welcomed the research and they were eager to cooperate. This reciprocity is reflected in the results of the survey, as most people were keen on the idea of having feedback administered by their machines.

Awareness, knowledge and the willingness to save energy

Results have indicated that not all participants (*M* = .88, *SD* = .33) were aware that idle running machines could be turned off, in order to reduce consumption of energy. Although, almost everyone (*M* = .94, *SD* = .24) was informed of the fact that machines still consume energy, when they are idle and they are waiting for the next product to arrive in order for it to be processed.

Nearly everybody (*M* = .93, *SD* = .26) had indicated that they would turn off a machine when he or she would be equipped in doing so. Taking into consideration that only half of the people (*M* = .50, *SD* = .52) presently are allowed to turn off a machine, this goes to show that it is important that a machine operator is able to turn off a machine, in situations when the machines are running idle. The survey feedback that has been provided by the employees indicates that employees are aware and willing to receive feedback and reduce energy, but unfortunately are not authorised to turn off idle machines.

Feedback stimulus material

As illustrated by Figure 2.1 and by the questionnaire that is provided in Appendix A, participants were additionally presented with nine different forms of factual and social feedback. These same participants were asked to rank the type of feedback, that they would prefer to be used and attached to receive, as displayed on machine screens.

After completion, results have indicated a very strong preference for the Power Gauge in the category of Factual Feedback (*M* = 7.64, *SD* = 1.39) and in the category of Social Feedback, a preference for the Emoticon (*M* = 5.50, *SD* = 2.88) can be seen in Figure 2.2 below. In this figure, the scale of preference ranges from 1 to 9, where 1 is least preferred and 9 is the most preferred.

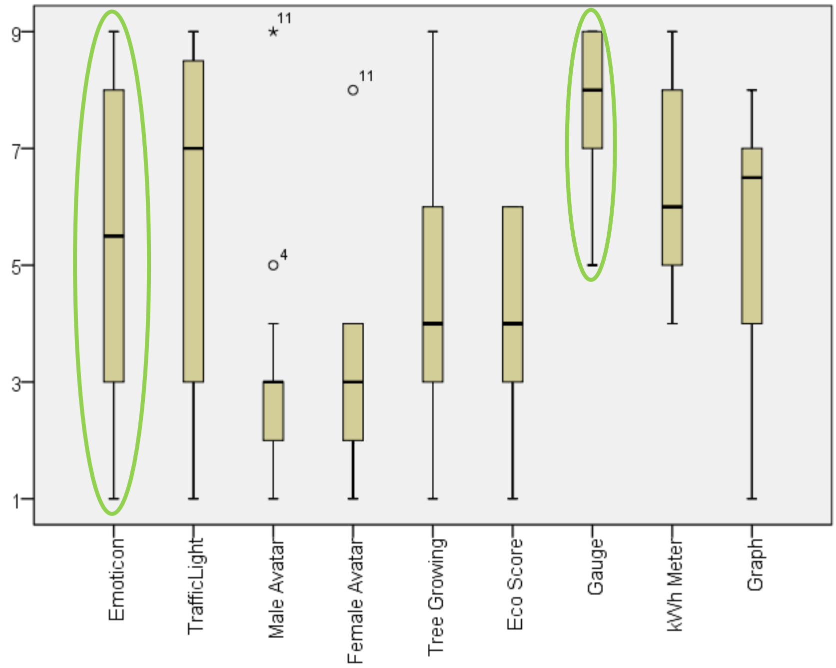


Figure 2.2. Box plot of the feedback preferences.

The results further indicate that The Traffic Light (*M* = 5.88, *SD* = 2.99) and the Graph-feedback type (*M* = 5.57, *SD* = 2.31) were also preferred more than Factual Feedback, but they were not as popular as the Power Gauge (*M* = 7.64, *SD* = 1.39). Perhaps these sorts of displays are more popular, because they are more used in the work environment where other feedback types are not used at all. Namely, the Traffic Light feedback type is commonly displayed on equipment in industrial manufacturing, in order to indicate the machine's running or its error state, as shown in Figure 2.3. The Graph and Gauge feedback types are, for example, used on the SCADA screens of various types of machines in order to display production information, as shown in Figure 2.4.

Figure 2.3. Machine stack light.

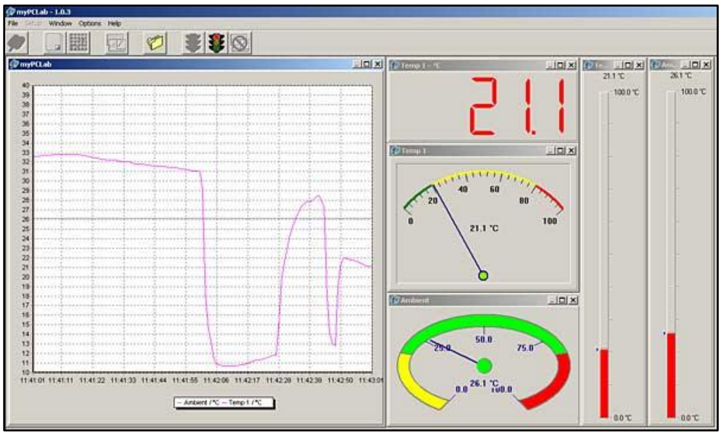


Figure 2.4. SCADA screen

By providing energy consumption indicators for machines, like a graph, a gauge, or a digital energy meter, any machine operator could easily recognize when the machine is still running or when it is in idle state, and judge whether to turn off the machine or not. Although there are various sustainability assessment tools available, these tools are generally complex, and they require large amounts of data and employees require technical expertise to utilize them (Paju, et al., 2010). In order to simplify these assessment tools, feedback that is presented to the machine operator should be as easily comprehensible as possible. This lack of comprehension could very well be why some off the types of feedback which were not preferred, such as the Avatars, the growing Trees and the Eco Score. Factory personnel are not used employing to such complex kind of displays and they may be considered as too complicated to understand, just as Paju, et al. (2010) have pointed out in their research.

Despite the fact that most of the participants were employees from a different department in the factory, our study has still provided us with such encouraging information in regard to developing factual and social stimulus materials for our subsequent study (study II). According to the results from this study (study I), we have selected the Power Gauge as our factual feedback and Emoticons as our social feedback, which is to be implemented in further field research (study II).

3. Study II: The energy engagement experiment

3.1 Introduction

In order to answer our research question: "What is the effect of factual versus social feedback given to machine operators, on Auxiliary Energy consumption in a manufactural environment?", the selected two types of feedback stimuli from Study I were used in order to set up this research experiment.

In Study II, these forms of feedback where used to test Hypothesis H1: "Factual & Social Behaviour will make the participants behave in a more energy efficient way". The effects of factual and of social feedback on energy reduction were measured in a real manufactural environment, rather than in a controlled laboratory setting. Moreover, we hypothesize (H2) that participants who receive social feedback will be able to shorten the machine's idle time more often than participants who receive factual feedback. Finally, in this study (study II) we have investigated our final hypothesis H3: "Less energy will be consumed by the machines when feedback is provided to the machine operators, than when operators receive no feedback at all." by means of monitoring the machines energy consumption during a field experiment.

Study I has indicated that feedback given through an emoticon might have a strong social influence on energy consumption. Study I has also shown that feedback given through a Power Gauge might have a strong factual influence on energy consumption in an industrial factory environment, that seeks to reduce its energy consumption.

In study II, as argued for by Börner (2012) and Geller (2002), the feedback was provided interactively and directly (live) to the machine operator. Feedback has also proven to be more valuable when it is provided more frequently (Abrahamse, 2005). Respectively, the feedback responds instantly (live) to the machine's energy consumption, through a real-time measurement of the machine's consumed energy and through an automatic and on-the-spot calculation for a feedback response, that is dependent on the actual power level consumed. In other words, the feedback responds instantly, determined by the behaviour of the participant (the factory employee).

According to the eight-step design process of Fogg (2009b), the target's behavioural change should be easy to implement. Befittingly, we have tried to develop an easy assignment for the participants which incorporate only one activity, they would have to perform during the course of their normal work. When they received factual or social feedback, the machine operators were requested to push a button to turn off the machines.

3.2 Method

The research has been conducted at Takumi Precision Engineering Ltd. in Limerick, Ireland. This company is a precision engineering manufacturing company which generally produces products for the medical industry. It produces for example, metal orthopaedic implants, such as illustrated in Figure 3.1 below.

Figure 3.1. A metal hip replacement.

In this factory, two Computer Numerical Control (CNC) cutting machines (as illustrated in Figure 3.2) had been monitored.

Figure 3.2. Left: a Miyano ABX-64SY Two Turret Turning Centre, Right: a Doosan DNM 350/5AX 5-axis machining centre.

3.2.1 Participants

Five male machine operators (aged 27-46, *M* = 36, *SD* = 7.62) employed by a precision engineering company, have participated in this study. During the experiment, the machine operators have worked on two precision milling machines, as they would normally do during their work. Three participants were working the day shift (from 08:00h to 17:00h) and two were working the night shift (from 17:00h to 02:00h).

Considering there were only two machines available for the research, a maximum of five participants had been at one's disposal available, as these participants were the only employees that were operating the two machines.

If we were to follow an a-priori power analysis, this research would have needed thirty-four participants in order to obtain a power of .80 (*Effect size d* = 1, *two-tailed α* = .05). Since the amount of participants was fixed to five participants, we have enabled the participants to perform diverse trial experiments to counterbalance the relatively low number of participants. A new power analysis has shown us that, with five participants, we would need a minimum amount of nine trials experiments per participant (thus forty-five in total), that would bring us to a power value of 0.804.

For the completion of study II, we have executed the research over two week's time. In this timeframe, we were able to let the participants complete 457 trials in total. As a result, a power value of 1 was obtained. A power value of .9917 had been obtained when each participant had completed 20 trials, thus equally 100 trial experiments in total.

Even though the statistical power has proven to be sufficient for this study, the fact that only 5 participants would be used to personify a much larger population of machine operators, these interpersonal differences could potentially bias our results. For example, if one of the five participants (which represents 20% of the population sample) is not willing to cooperate with the research, or has a very distinct personality compared to the others, generalizing the results would become rather difficult. This possible confounding variable has therefore been thoroughly analysed and discussed in chapter 3.3.

3.2.2 Experimental design

This field experiment encompasses two conditions: factual feedback and social feedback, which are going to be displayed on a screen. During this experiment, the energy consumption and the machine operating time, per product (which equals energy intensity per product), is being measured. This experiment is a 2 (Feedback type: factual feedback vs. social feedback) Within Subject Mixed Design as illustrated in figure 3.3.

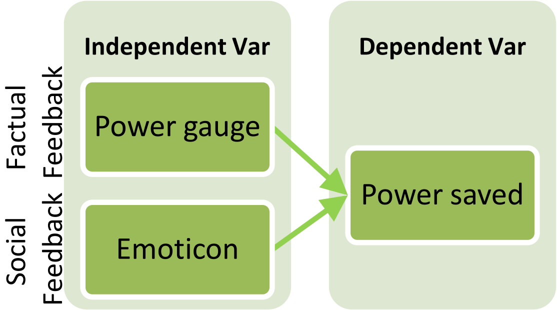


Figure 3.3. Research design: a 2x1 Within Subject Mixed Design.

The measured Energy Intensity (energy consumption and machine operating time per product) has been compared to a condition without the giving of any feedback and without the possibility to turn off the machine. In the past, the machines were not able to be turned off, because there was a chance that the cutting tool might misalign when the operator would try to restart the machine. As a result, the machines were kept on running all of the time. That is why, making comparisons to a control group was just not possible back then. However, we have tried to emulate the control condition as close as possible, by comparing the saved Energy Intensity to the actual energy readings, during times of factual feedback and we have compared the readings during times of displayed social feedback.

During this research experiment, two similar milling machines (as illustrated in Figure 3.2) that are being controlled by five operators, where monitored. Both manufactural environments had been provided with the same feedback conditions: there had been one week of experiments with a factual feedback condition and there had been one week of experiments with a social feedback condition. As a means of minimising the learning effect, the order of provided feedback had been varied differently for both of the two milling machines. Machine number 1, The Miyano CNC milling machine, had started the first week of experiments with the factual feedback condition and the second week of experimenting was started with the social feedback condition. Machine number 2, the Doosan CNC milling machine, had commenced the first week of experiments with the social feedback condition, followed by the factual feedback condition in the second week of experimentation.

In order to investigate the effects that the received feedback might have had on the operators' professional behaviour, a base line power consumption value (control variable) had been simultaneously put into effect during both feedback conditions. Considering the fact that the machines were not allowed to be turned off at all during research, it was simulated that they had been turned off. This method of executing the variables is further explained in chapter 3.2.4.1.

3.2.3 Dependent variable

Throughout the experiment, the machine's consumed energy had been recorded, as well as the date and the time in order to analyse the 'Energy Intensity' per product cycle. Certainly, we were not immersed in the full product manufacturing cycle, but we were primarily interested in the non-productive period of the production cycle (i.e., the machine's idle time and machine's turned off duration). The total production time of a product consists partially either of 'Run Time', or 'Idle Time', and, in case the turn off button had been pushed, it partially consists of 'Off Time'. This is illustrated in Figure 3.4 below.

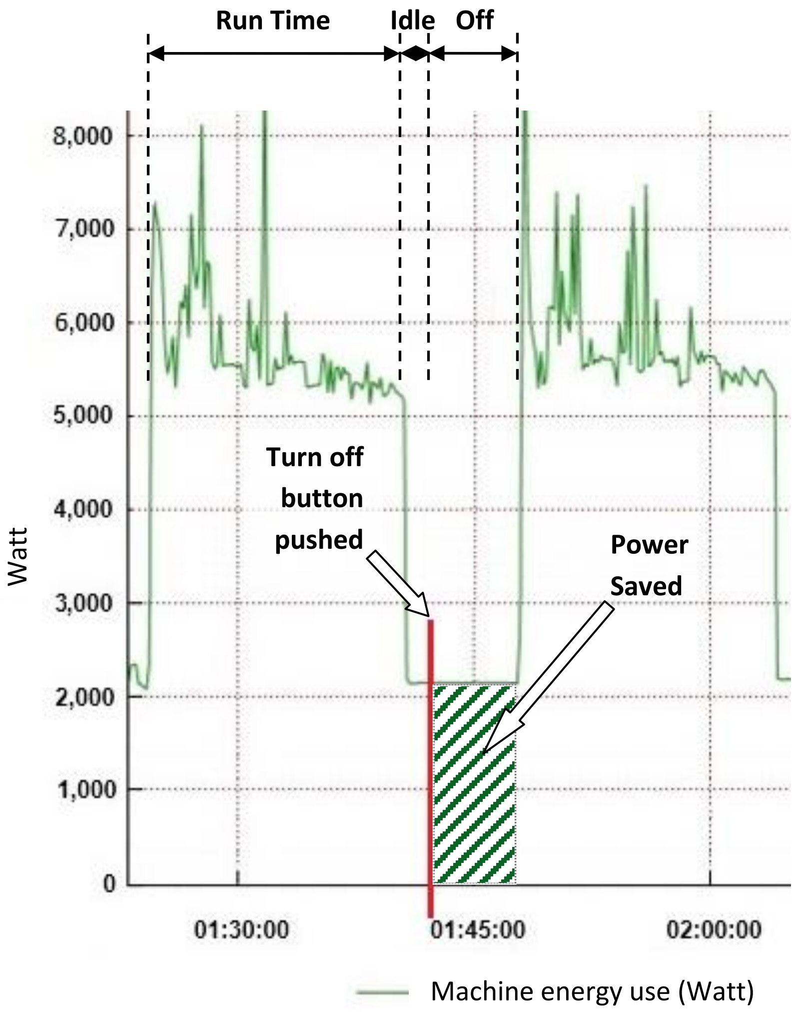


Figure 3.4. Energy saved indication

The power that the machines used during the Off Time, was the key indicator (the dependent variable) in measuring the enhancement of energy efficiency: the greater the Off Time was, the lesser the amount of energy that is wasted by an idle machine when it waits for the next product to arrive for further manufacturing.

3.2.4 Materials

To be able to provide feedback to the machine operators during their work, we had developed two feedback-providing devices, whereas they can be seen in Figure 3.5. These two devices are entirely identical; they can only be distinguished by the type of feedback that are displaying. They both consist of a screen with an adaptable height frame, which has been mounted on top of an encased Programmable Logic Controller (PLC). The screen and PLC are erected on top of an office drawer, that houses a computer, as is being illustrated in Figure 3.5.

Figure 3.5. Two identical feedback devices; consisting of a screen, an encased PLC and a computer.

The PLC is used to measure the machine’s energy consumption and it is used to calculate and to process the suitable feedback towards the screen, whereas the computer is used in order to log these feedback signals that are transmitted by the PLC. These logs are documented for data analyses, afterwards. The monitor screen displays the appropriate feedback towards the machine operator. The remainder of the hardware in this system will be additionally discussed in chapter 3.2.4.1 and the software (the PLC software and then displayed feedback on the screen) will be discussed in chapter 3.2.4.3.

Practically, the feedback system consists of a push button and it consists of three current transformers that measure input, and the feedback system includes a Programmable Logic Controller (PLC) with special software in order to process the input and in order to configure an output (the given feedback) onto a computer screen. A normal computer is used to log the input and output that are later on used for data analyses.

In order to process the input (the measurement of power and the push button actions) and to process output (feedback and recorded data), we have developed a type of software for the PLC (written in Structured Text code) and we have developed our own software for the computer (written in Java code).

The PLC, operated by this new software, has been able to measure the current transformers’ output (power consumption values of the machine) and the PLC has been able to measure the activity of the push button. The PLC processes these measurements and, according to the software, the PLC sends the signals to the computer, in order to display the feedback towards the participants.

The computer, directed by our software, has then received the PLC and it has displayed this feedback on the screen that is secured to the computer. The computer has furthermore stored all the received data locally on the hard drive. These data will be analysed in detail from chapter 3.2.4.1 onwards.

To be able to create this kind of PLC software, an energy profile (base line) of the machine’s energy consumption has to be measured and it has to be identified, at least a week prior to the actual research experiment. At this stage, product manufacturing cycles had been identified. These were based on the power profiles charted from operating the machines. With this information, perimeters had been created in order to initiate feedback responses at the right moment during this research experiment. These measurements indicate that the machines were unproductively idle at a power consumption level of approximately 2,100 watt, and that the machines were busy manufacturing a product while consuming electricity at a power level of 5,000-10,000 watt, depending on the size of the product piece manufactured and depending on the type of material that is used. Cutting a small aluminium piece uses far less energy than for instance, cutting a large stainless steel product piece due to its size and the hardness of the metal. Either way, data conclusions show that when the machine is cutting a product, the energy level will rise above 3,200 watt, this being independent of the product size and choice of material that is being used. This positions the first threshold: any energy exhausted above 3,200 watt is categorized as an operating machine.

The second perimeter, in order to indicate the margin between ‘idle’ and the ‘power off’ state, was set on 450 watt. Therefore, any consumption between 450 and 3,200 watt is regarded as an idle machine. In other words, the machine was not processing a product, was not turned off, and so, the machine is waiting and consuming auxiliary energy. However, if the power dropped below 450 watt, it is assumed that the machine had been turned off completely.

A typical power consumption, that characterizes the manufactural process of two products, has been illustrated in Figure 3.6. As you can see, in this figure, energy thresholds were defined which were used to establish the appropriate type of feedback that is to be given to the employees via the screens.

During this experiment, the dependent variable ‘Energy Saved’ had been calculated by multiplying the time, between when the button is pushed and between the starting times of a new product, with the idle energy usage. This can be methodized through the following formula (1).

$$\text{Energy saved (kWh)} = (\text{time between button pushed and new product start}) * \text{Idle energy} \qquad (1)$$

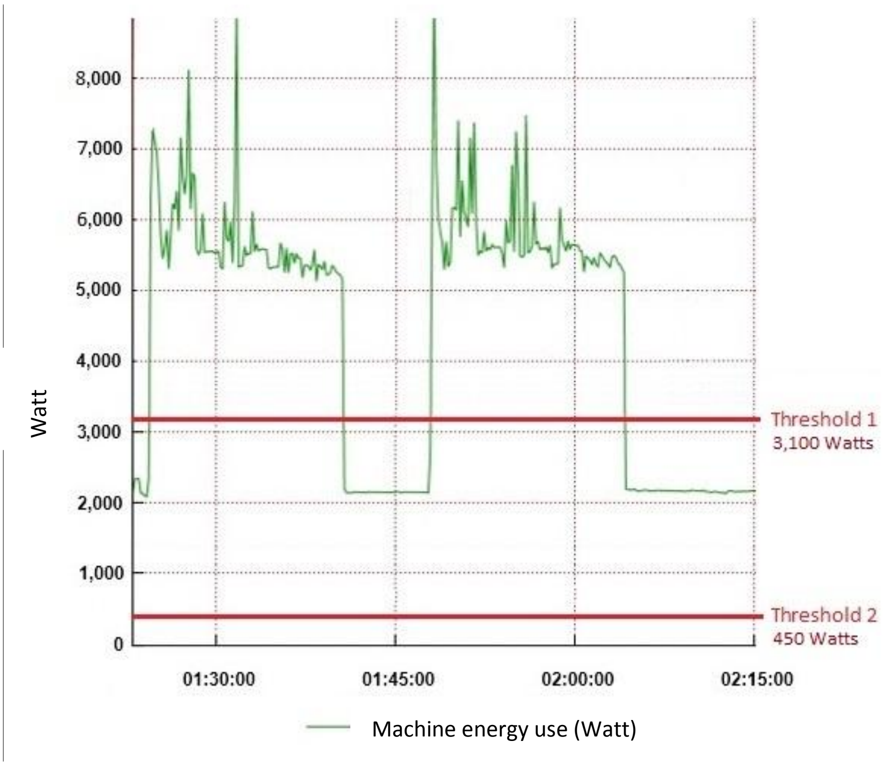


Figure 3.6. Energy consumption that is typical of a fully operating machine.

The PLC software had been formulated in order to display feedback onto a computer screen. Different types of feedback were given to the participants, according to the energy limits. The open source code of the 'Structured Text PLC software' can be studied in appendices G, H and I.

Our schematic overview of the whole feedback system is fully illustrated in Figure 3.7 below. Additionally, a detailed block diagram of the PLC, with its peripherals, is demonstrated in Appendix C.

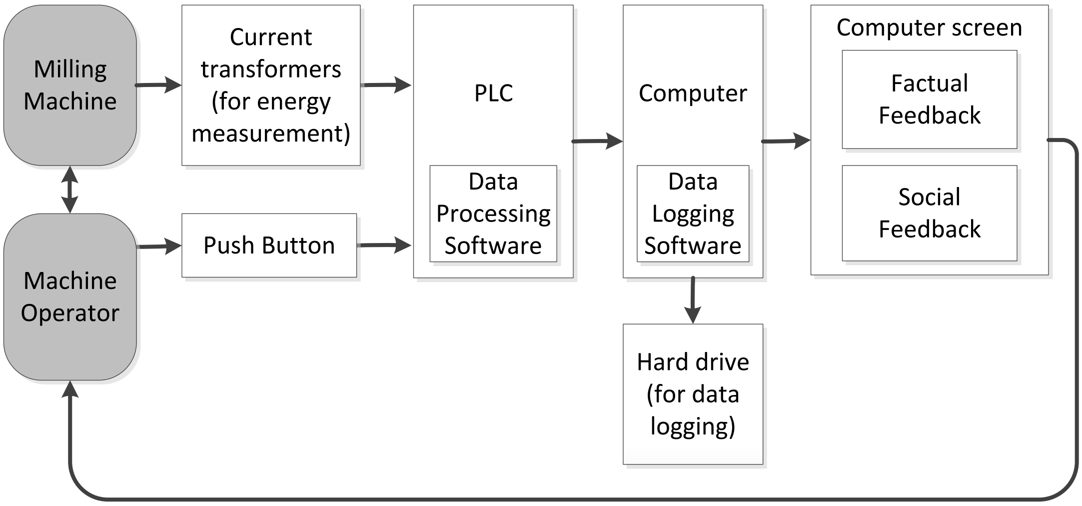


Figure 3.7. A schematic overview of the energy efficiency feedback experiment.

A photographic chart showing the research environmen, is presented in Figure 3.8.

Figure 3.8. The Miyano CNC cutting machine as used in the research environment.

3.2.4.1 Input materials

Three current transformers have been installed into each of the two milling machines, in order to measure the energy consumption of the two machines (3-phase).

In correspondence with the study of Ham & Midden (2009), where the participant had to push buttons in order to cut down on energy, we had also made a push button as a means to simulate the act of turning off a machine when a product was finished. This button had to be developed because shutting down the machines in this factory was not possible due to the chances of misaligning the cutting tool when the machine would restart, as clarified previously in chapter 3.2.2. Accordingly, we have prepared a simulation pushbutton in order to meet the reality of shutting down a machine as close as possible. By pushing this button, it does not actually turn off the machine, but the turning off is just being simulated so the corresponding feedback can be given.

The pushbutton, as can be seen in Figure 3.9, bares the description: “I would like to switch off the machine now” in order to signify the function of the button.

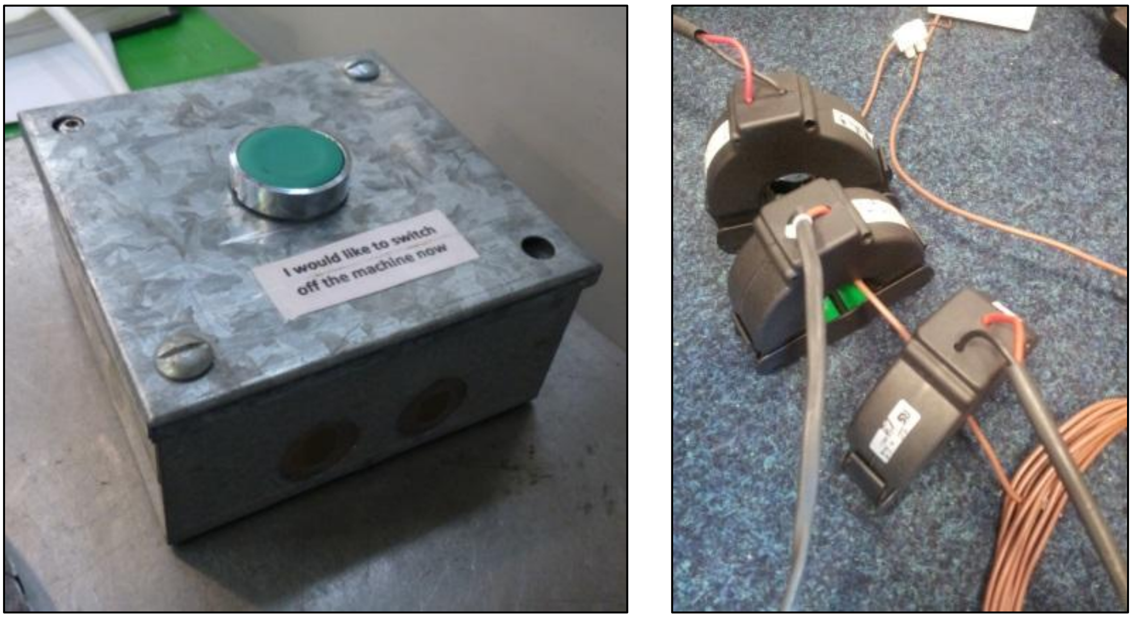


Figure 3.9. Left: a pushbutton to switch off the machine. Right: three current transformers to measuring a 3-phase current.

3.2.4.2 Input and output processing devices

A Programmable Logic Controller (PLC), which can be seen in Figure 3.10, has processed and converted the provided input (the push button signal & the current transformation) into output (feedback) onto the computer:

Figure 3.10. The PLC with its components, such as a power supply and input - and output - connections.

The computer has then converted the PLC output-variables into visual feedback on the screen. The computer also store these output signals and these programmed states onto the hard drive, to be used for data analysis afterwards.

3.2.4.3 The displayed feedback

Depending on the selected feedback condition (factual or social) a different type of output was displayed on a computer screen. A power gauge was used as a means of factual feedback and an emoticon was used as a means of social feedback.

The Factual Feedback condition

The power gauge on the screen displayes the current consumption of energy by the machine.

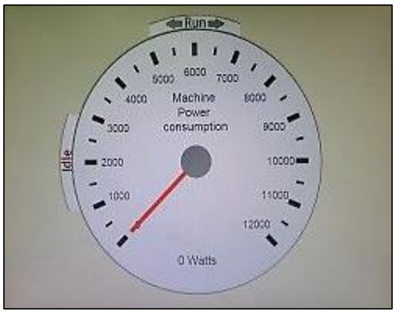


Figure 3.11. Factual Feedback being displayed on a screen.

The Social Feedback condition

Based on research that had been completed by Ham & Midden (2014), in which where the participants receive on-screen social feedback, we have developed our own unique on-screen social feedback through the use of emoticons, as had been indicated in Study I. During our research experiment, social feedback was provided on-screen to the participants through the use of diverse emotional expressions, as illustrated in Figure 3.12 and Figure 3.13.

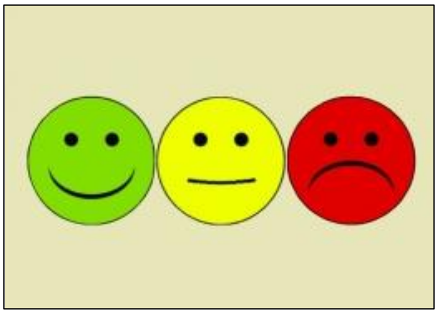
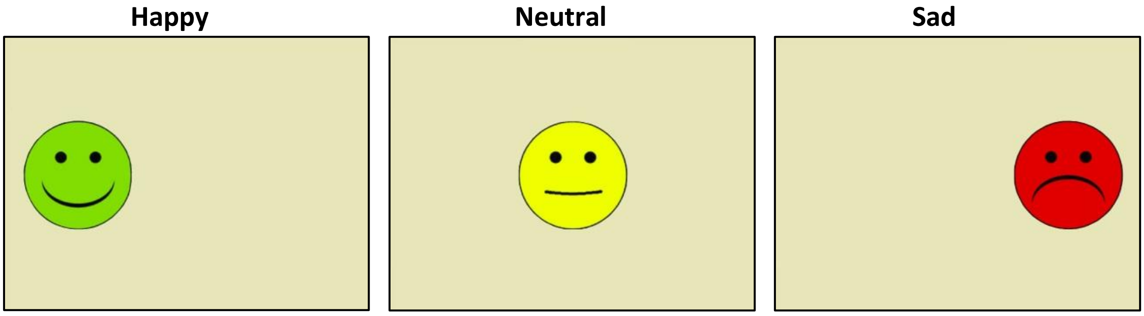


Figure 3.12. Social Feedback displayed on a screen.

Depending on the machine operators' actions, one of the following emoticons is presented on the screen.



Happy **Neutral** **Sad**

Figure 3.13. Three states of Social Feedback as shown on a screen. From left to right: Happy, Neutral, and Sad.

At last, after the research had been completed, we employed a final questionnaire amongst the participants, in order to provide us with distinguishing information about their participation. The questionnaire, which all participants have completed during the final day of the research experiment, will be discussed in chapter 4 (Study III).

3.2.5 Procedure

Initially, all participants, who were operating at both machines (machine 1 & machine 2) were kindly asked if they were willing to participate. It has to be noticed that they were all eager to join and to cooperate without asking for any kind of reward.

Prior to the first week, the two feedback systems had been connected to machine 1 and machine 2 and they were all fully functioning. During the first morning, all participants were welcomed and they were briefed about the research. The participants were informed through a letter, holding instructions about the new pushbutton and its use. This letter can be read in Appendix D.

The partakers were all requested to turn off their machine by pushing the new button. They were advised to do so when they would normally turn off the machine, if turning off the machine had been possible. Ideally, this would have been right after every product had been finished.

Throughout the whole of the research, two feedback conditions were initiated: a Factual Feedback condition for Machine 1, the Miyano CNC milling machine, and a social feedback condition for machine 2, the Doosan CNC millling machine.

All along the Factual Feedback condition, the participant would have received the feedback through the use of a power gauge, which had been presented on the computer screen, as was illustrated previously in Figure 3.11. Displayed on this screen, the participants would be able to read the power (in watt) of the machine's current energy consumption. When the machine operator pushes the button (to simulate turning off the machine), the gauge dial automatically reverts to 0 watt. This was done only for simulation purposes and it did not actually turn off the machine. The machine would still be running in idle mode, just as it normally would. The power gauge will continue the machine's energy consumption readings after the machine was switched into running mode again, in order to manufacture the following product.

During the Social Feedback condiction, the participants would have received an emoticon displayed on the screen, as had been illustrated in Figures 3.12 and 3.13. Depending on the machine's operational mode (run, idle, or in simulated off state), the machine operator receives the corresponding feedback mode visible on their screen.

When a product is processed, the participant receives a neutral (yellow) face as feedback. Right after the product is processed, the machine reverts into idle energy consumption mode. During this state the machine operator is expected to remove the finished product and to turn off the machine by pressing the pushbutton. When the machine operator does not turn off the machine after a product had been finished, the sad (red) face was presented for 15 seconds. This would provide the machine operator with some time in order to remove the product from the machine, before definitely turning it off. A happy (green) face was shown to the operator, immediately after pressing the button during the machine's idle state.

In order to explain what feedback was presented, in which condition, a flowchart was added to appendices E and F. Furthermore, the source code for the PLC program is provided in Appendices G, H and I for more detailed information regarding the event procedures.

Just as was explained at the beginning of this chapter, the factual feedback condition had been applied to machine 2 in the first week, and the social feedback condition had been applied to machine 1. In the course of the second week, the displayed programming was switched from social feedback to factual feedback and vice versa during the final week.

After the trials had been finalised in the second week, the participants completed a last questionnaire. After finishing the answers of the questionnaire, the participants were debriefed and thanked for their participation. Their questionnaire is more elaborately discussed in chapter 4 (study III).

3.3 Results

In order to compare the effect that feedback has on the amount of time a machine is turned off, a Mixed Model Analysis was performed with the conditions of factual feedback, social feedback and no feedback. Our dependent variable was named 'Energy Saved' (in watt-hours). We have found that the type of feedback influences the amount of energy that is saved. ($F_{1,\ 453}$ = 13.83, *effect size (Cohen's d)* = 1,478, p < .001), thus confirming our hypothesis (H1).

More specifically, the estimates of the fixed effects reveal that when participants receive social feedback, a higher 'Energy Saved' score (*M* = 231.93, *SD* = 61.22) is achieved, than when participants receive factual feedback (*M* = 141.40, *SD* = 61.28). Therefore, further confirming our hypothesis (H1), Factual & Social Behaviour will make the participants behave in a more energy efficient way. The fact that the mean of 'Energy Saved' in both feedback conditions is a positive mean, confirms our third hypothesis (H3): Less energy will be consumed by the machines when feedback is provided to the machine operators, than when operators receive no feedback at all. However, it has to be noted that the 'No Feedback' condition had only been a measurement of the actual energy that is consumed during all feedback conditions. The 'No Feedback' condition was therefore not a unique and distinguishing condition as it ought to have been in order to fully confirm this hypothesis (H3).

The energy that was saved during the social feedback condition had been significantly higher than the energy that was saved during the factual feedback condition. The difference (*M* = 90.53, *SD* = 24.35) confirms our hypothesis (H2) that machine operators, who receive social feedback, reduce the machine's idle time more than machine operators, who receive factual feedback.

These findings are in harmony with the second hypothesis (H2), that theorizes that turning off the machine sooner in order to reduce the total production time, will improve energy savings. When evaluating which feedback condition has had the largest impact on energy, when the machine was turned off, the proportions of the total non-productive time were analysed. Reasoning that the total production time of one product equals a 100%, the results of a 'Mixed Model' analysis have indicated that participants, who have received factual feedback, have thus reduced the total production time with 2.9% (*M* = .029, *SD* = .007). Participants who have received social feedback, have reduced the total production time even down to a 5.1% (*M* = .051, *SD* = .007, $F_{1,455}$ = 16.82, effect size (Cohen's d) = 3,143, p < .001), as is illustrated in Figure 3.14. The result have validated our second hypothesis (H2), that participants who have received social feedback has shortened the machine's idle time to a greater extent, than participants who have received factual feedback.

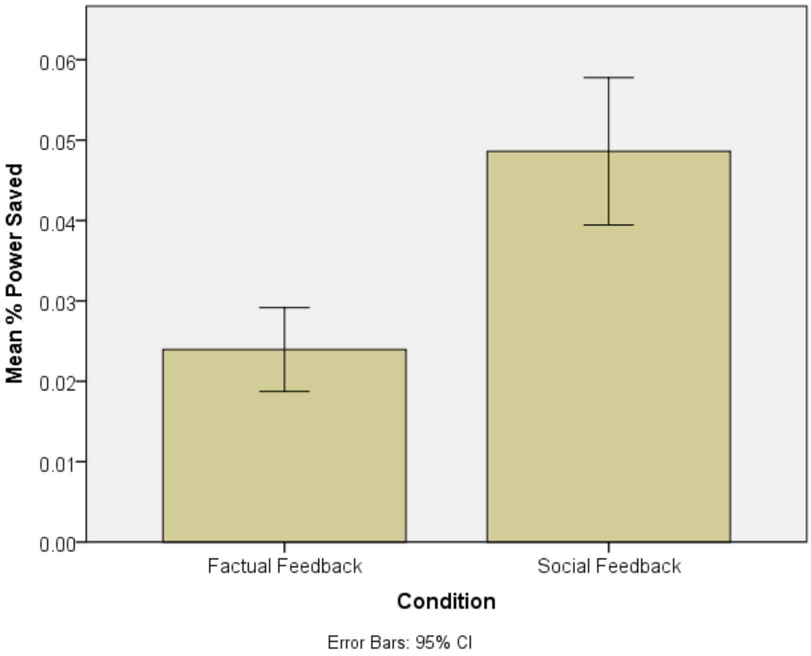


Figure 3.14. Percentages of the energy that is saved when a machine is turned off.

The saved energy per feedback condition differs between the two types of machinery. The energy that is saved during shut down periods by the Miyano machine is only 88 Watt on average (*M* = 87.673, *SD* = 163.332) when compared to the Doosan machine, which can save 335 Watt on average (*M* = 334.583, *SD* = 475.961, $F_{1,\ 455}$ = 56.627, *p* < .001). Despite this difference in terms of absolute energy savings, the machine operator behaviour had not been biased by the type of machine. In other words, the operator's behaviour was not affected by the type of machine, and therefore, the operators would not have behaved differently if they had to control the other type of machine. The fact that, the absolute savings by the Doosan machine were significantly higher than at the Miyano machine, was due to the fact that the Doosan machine simply consumes more energy than the Miyano, when then machines are idle. Hence, the type of machine had not proven to be a significant confounding variable in order to save on energy ($F_{1,\ 453}$ = .104, *effect size (Cohen's d)* = .037, *p* = .747).

Because there were no significant interpersonal differences to be found, (the participants did not behave differently from one another), the small sample size of five participants had not been a limitation in our research experiment. Additionally, the type of machine was not found to be a cofounding variable. None of the participants and neither type of machine have proven to be an outlier. As a result, they were all included in our experiment.

A full list of results of the ‘Mixed Model’ analysis is present in both Appendix J and Appendix K.

3.3.1 Exploratory research: monetary energy savings

The results above pertain to the productive periods (i.e., normal working hours during the day and the night shift). If we were to consider the non-productive periods during the week (i.e., lunch, coffee breaks, moments between shifts, and even weekends), we then could generate the following energy savings calculation:

At Takumi Precision Engineering Ltd, a typical work schedule was maintained. This timetable is illustrated in Table 3.1 below.

Table 3.1. Weekly work schedule at Takumi Precision Engineering Ltd.

Weekly work schedule

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	**Total**
Working hours (day shift)	8	8	8	8	5	n/a	n/a	
Working hours (night shift)	8	8	8	8	n/a	n/a	n/a	
Productive hours	**16**	**16**	**16**	**16**	**5**	**0**	**0**	**69**
Non-productive hours	**8**	**8**	**8**	**8**	**19**	**24**	**24**	**99**

A typical week at Takumi comprised of 69 hours of mechanical production and 99 hours without any mechanical production. During these productive hours, as previously had been concluded, 2.9% energy could be saved by providing factual feedback, and 5.1% of total energy could be reduced by giving social feedback. This means that 2.9% of 69 hours are 2 hours of auxiliary energy that had been reduced (per machine per week) through the use of factual feedback, while 5.1% of 69 hours is 3.52 hours of auxiliary energy that had been reduced (per machine, per week) through the use of social feedback.

Likewise, 2.1kW is consumed during an hour of idling auxiliary equipment per machine, which equals €0.20 * 2.1kW = €0.42 per hour per machine, or €2.10 per 5 machines, which are on site at Takumi Precision Engineering. Savings could therefore be €2.10 * 2.00 = €4.20 a week (or €18.20 a month) for 5 machines by using factual feedback, or €2.10 * 3.52 = €7.39 a week (or €32.03 a month) for 5 machines; through the use of social feedback during the productive hours.

These monetary savings may seem very low; however, when the non-productive hours are taken into account, savings increase abundantly. During the non-productive hours (i.e., lunch, coffee breaks, moments between shifts, and weekends), the machine is normally passively idle the whole time. By encouraging the machine operator to turn off the machine after having produced the last product during his manufacturing period, the amount of energy can be substantial. Results indicate that the machines were turned off in 89 out of the 227 trials throughout the factual feedback condition. This would mean that the machines had been turned off 89/227*100% = 39.21% of the time. Throughout the social feedback condition, the machines were turned off in 136 out of the 230 trials. This would mean that the machines had been turned off 136/230*100% = 59.13% of the time.

By taking the 99 of non-productive hours into account, we can derive that 38.82 hours (39.21% of 99 hours) of machine idling can be diminished by providing the machine operator with factual feedback. This could represent a savings of €0.42 * 38.82 * 5 days = €81.52 per week, or €353.26 per month for all five machines at Takumi. By presenting social feedback could save even more on energy: €0.42 * 59.13% of 99 hours * 5 days = €138.61 per week, amounting to €600.63 per month, for all five machines at Takumi.

Again, it ought to be noted that these calculations are based on the difference between conditions of factual and of social feedback and are based on a condition in which the operators are unable to turn off their machines in order to make a fair comparison and in order to fully understand the difference between the feedback and the no-feedback conditions, this study could be duplicated, while participants would then be able to turn off their machines during feedback and no-feedback circumstances.

3.3.2 Exploratory research: improvement of productivity

Results indicate that in addition to saving energy through the use of factual and through the use of social feedback, the production time had been improved as well. The productivity was improved, because the products had been able to be loaded and unloaded earlier in the machine, which in its turn has decreased the non-productive time. The machine operators had reduced the milling machine's non-productive time (turned off time + idle time) from 31.3% (*M* = .313, *SD* = .026) of the total time while receiving no feedback, to 23.4% (*M* = .234, *SD* = .023) while receiving feedback on what to do. A reduction of 31.3% - 23.4% = 7.9% (*M* = .079, *SD* = .016) of production time was therefore achieved, per manufactured product.

This increase of productivity of +7.9% has been illustrated in Figure 3.15 below. The decreased production time allows the factory to produce 13 products (12 products * 7.9 * 100% = 13 products), while it would normally produce 12 products.

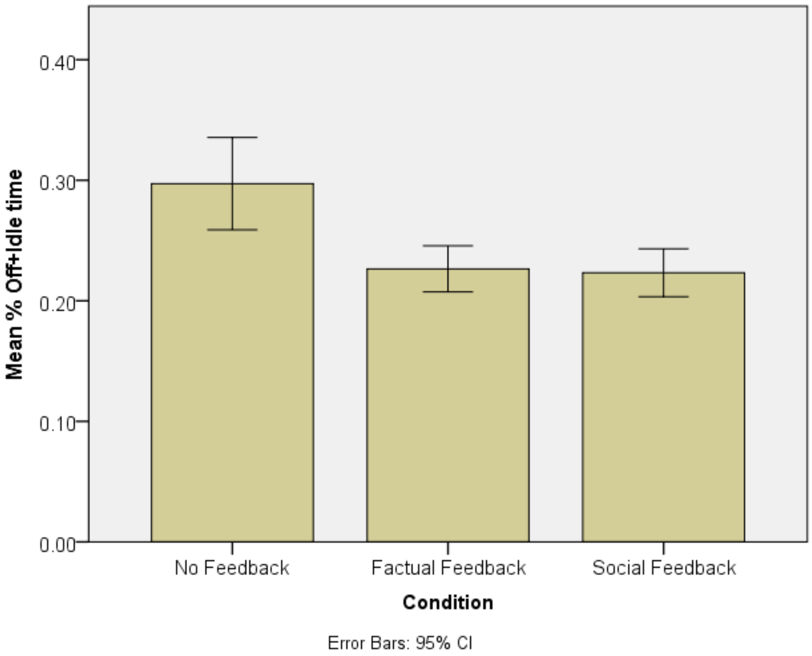


Figure 3.15. Percentages of the machine's non-productive time (idle time + off time) per feedback condition.

3.4 Discussion

The amount of energy that can be saved during production-time (M = 141 with factual feedback and M = 232 with social feedback, or €18.20 per month and €32.03 per month savings respectively) is a minor saving, when compared to the savings that can be made during non-production periods (€353.26 per month with factual feedback and €600.63 with social feedback).

DNV GL (2011) and Wising, et al. (2014) had already indicated an energy savings potential of 5-15%. However, this would only have been possible to achieve during productive hours through the use of social feedback in order to prompt the operators to turn off their machines. If non-productive hours are also taken into account, these predicted 5-15% savings could easily be achieved. However, our results are based on a comparison of feedback conditions with a condition with no feedback. We believe that this effect would be even stronger if the participants had been able to truly turn off their machines during both of the conditions.

By displaying factual feedback on the milling machines, 2.9% of the total energy was saved during production time, which equals a saving of 2.9% of energy consumption per product. However, by displaying social feedback, instead of factual feedback, 5.1% of energy could be saved.

The results of this study have been able to confirm that the adding of feedback to a machine's manufactural process has had a positive effect on the saving on energy. Results have suggested that wherever social feedback had been presented, the machine had been turned off even sooner than when factual feedback had been displayed.

A more thorough discussion is provided in chapter 5: General Discussion. Throughout this chapter, we will discuss how we have handled the small amount of participants, we will discuss the colour scheme we have used in our social feedback emoticons, and we will discuss why the machines could not be turned off during our research experiment. Furthermore, we will examine the monetary savings and the energy reducing potential that these feedback methods may contribute to a manufactural company.

4. Study III: Post-experiment survey

4.1 Introduction

Near the end of the research study a second survey had been directed in order to investigate the experiences of the participants during the course of this research experiment (study II). This study has further highlighted their views on the displaying of diverse types of feedback onto machinery in order to reduce energy consumption by those machines.

4.2 Method

4.2.1 Participants

The same five male machine operators (aged 27-46, *M* = 36, *SD* = 7.62), who have also participated in the research experiment of study II, have completed a succeeding survey questionnaire.

4.2.2 Materials

A survey has been distributed, in order to investigate the employees' experiences and the acceptance of the applied feedback onto their machinery.

The survey has been split up into four categories. Firstly, some general questions were asked, which included questions about the experience of receiving feedback in general. Subsequently, some social feedback related questions were asked. Following, questions have been asked about the received factual feedback, and lastly, there had been scope for their own comments and their own suggestions in the last part of the questionnaire.

The full survey is demonstrated in Appendix L.

4.2.3 Procedure

At the end of the final week of the research experiment (study II), this second survey was handed out to the machine operators and they were thanked for their excellent cooperation. In this survey, 28 Likert scale questions and 2 open questions had been answered and the survey had been handed back afterwards.

4.3 Results and discussion

Performing a Factor Analysis had not been advisable, because in this survey there are much more variables (28 Likert-scale questions) than cases (5 participants). Therefore, this questionnaire has been analysed graphically, as illustrated in Figure 4.1, Figure 4.2 and Figure 4.3. As can be seen in these figures, the Likert-scale ranges from 1 (strongly agree) to 5 (strongly disagree).

Because of poor statistical power, the results are used for differentiating purposes only.

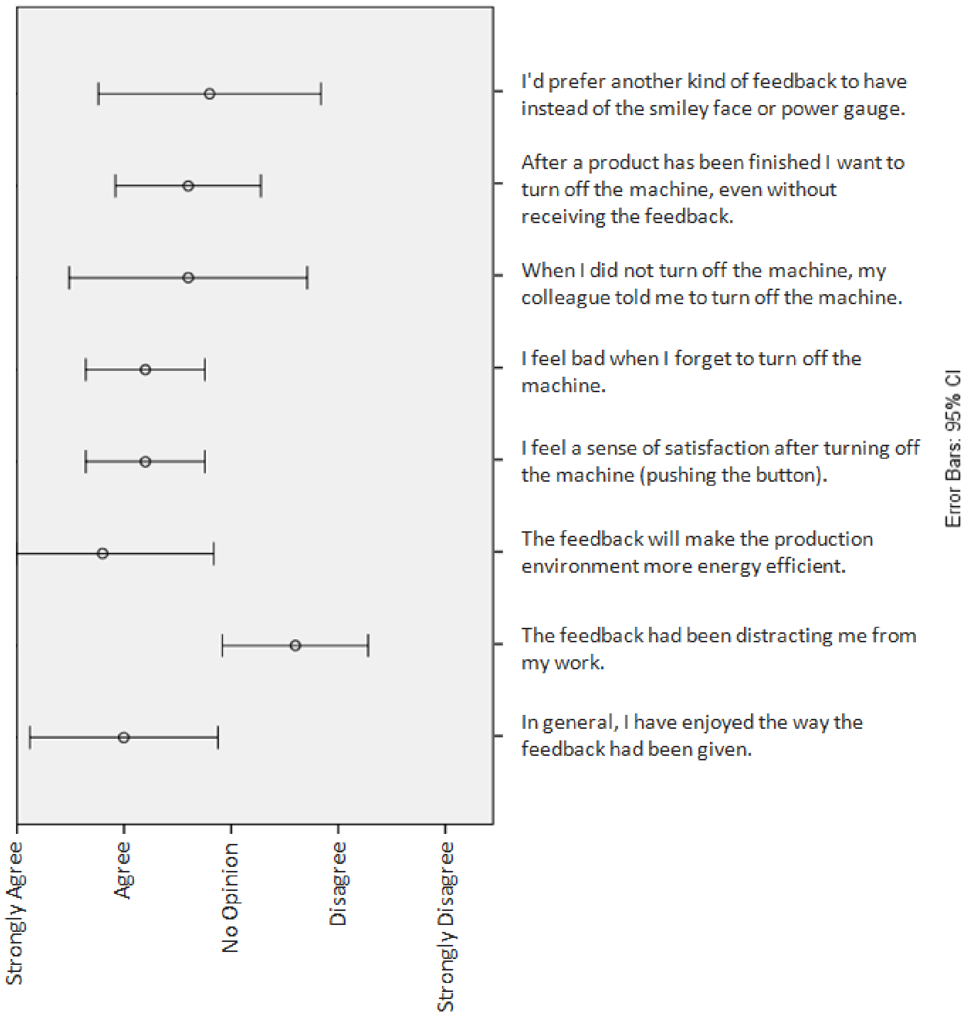


Figure 4.1. Survey study III: General questions.

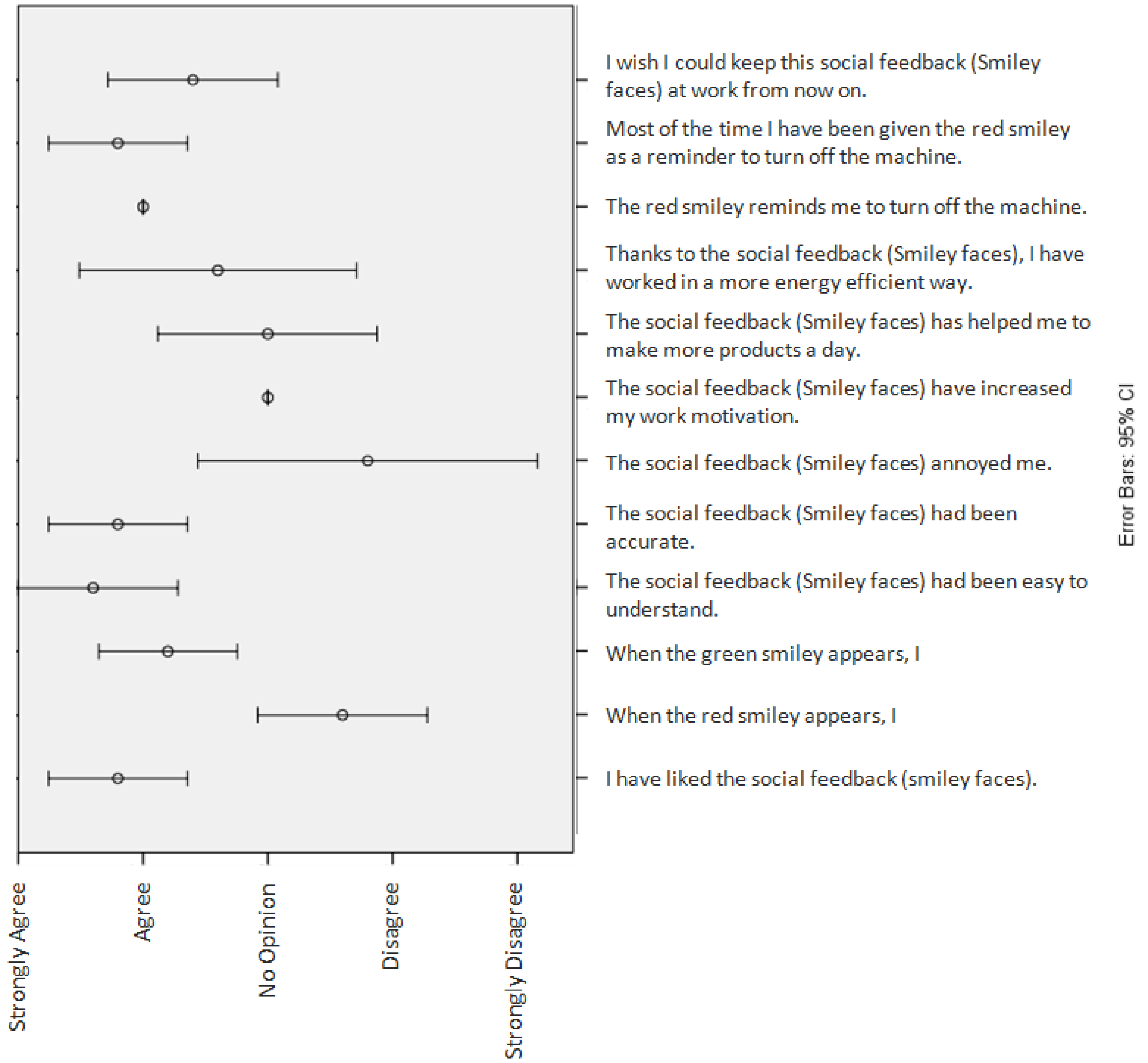


Figure 4.2. Survey study III: Social feedback questions.

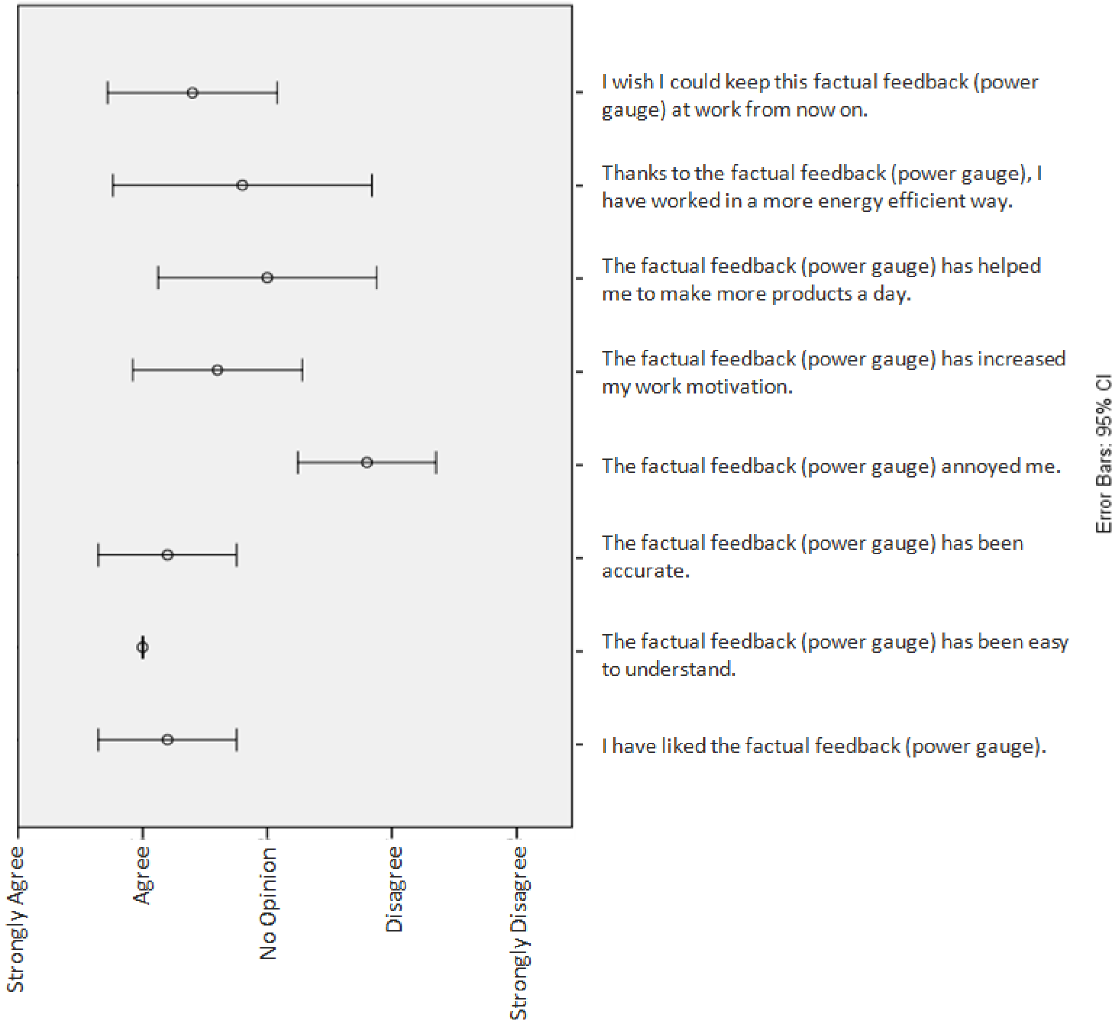


Figure 4.3. Survey study III: Factual feedback questions.

As can been concluded from the results of this survey, the machine operators have appreciated the presence of feedback in their work environment. In general, the participants remarked both types of feedback as easily understandable. They have liked the received feedback, whereas the social feedback was just a little more popular than the factual feedback. It seems that using feedback systems at Takumi Precision Engineering Ltd. In order to reduce energy would not be a big obstacle. Furthermore, the participants support the assumption that the feedback has facilitated in improving the energy efficiency during the manufactural process. Conclusively, the operators would like to continue using the feedback during their current and future manufactural work tasks.

Once more, these survey results of study III should only be treated as a descriptive study, due to the lack of significant statistical power.

5. General discussion

During the whole of this chapter, we will try to put our findings in perspective by reflecting on our original hypotheses and by discussing our outcomes; we will strive to answer the main research question: What is the effect of factual versus social feedback given to machine operators, on Auxiliary Energy consumption in a manufactural environment?

This research has been conducted in order to investigate the effect of factual and of social feedback in a manufactural environment, rather than in a controlled laboratory setting. Finding similar studies or similar industrial projects has proven to be rather challenging. Due to lack of time, lack of resources and absence of monetary funding, this industry does not focus on energy efficiency, nor does it invest in it. Conducting this research with a significant outcome could therefore be of great value to the manufacturing industry.

In order to save on energy, the focus of the industry should rather be on the auxiliary energy of Significant Energy Users (SEU's) (Cosgrove, 2011). By minimizing the auxiliary energy, during non-productive time periods, a significant amount of energy is able to be reduced.

Machine operators should be given proper instructions, information and indicators for when, and how to turn off their machine(s) in order to save on auxiliary energy. A great mechanism in providing feedback for the operator could be the illustration of social feedback on computer- or machine screens.

For each and every study, the results will be discussed in greater detail throughout the following chapters.

5.1 Study I: The pre-experiment survey

Prior to actual factory research (study II), a survey was distributed amongst the employees of a precision engineering company, in order to investigate the employees' factory energy reduction awareness, abilities, their willingness, and which kind of feedback they are likely to prefer during the research. Furthermore, this study's main goal was to inform the employees and to spark their interest in energy awareness (study II). Just like NRC (2015) has pointed out, that one of the key principles of energy reduction, is to engage the workforce in energy efficient operations. This has worked out quite well, as most participants of this survey (study I) where eager to join our research (study II) later on, without them asking for any kind of reward. However, most of the participants were not able to join the subsequent research (study II) because their role within the factory was different from being a machine operator.

In general, the participants have welcomed the research. Surprisingly, most of the employees were very willing to turn off idle machines in order to save energy; while most of them would not know how to turn them off, or in what situation they should turn them off. This is likely to happen, for they are not allowed to do so, because of possible machine misalignments at the start up, or because of other factors that might keep the machines running all of the time. Moreover, in many situations it is perfectly safe to turn off a machine after production hours. In these situations, opportunities may arise to be capable of saving on energy, without great effort. Hence, the floor manager should brief his machine operators on how and when machines are supposed to be turned off.

Besides the participants' willingness and abilities to turn off a machine, feedback material for the research (study II) was further explored. This approach has worked out quite well, as the participants early on felt that they were part of the research. Receiving following cooperation for the follow-up experiment (study II) therefore became straightforward. Participants have expressed the emoticon and the power gauge, as their most preferred form of feedback. These two types of feedback were therefore used at the energy engagement experiment (study II) later on.

5.2 Study II: Energy engagement experiment

This study was conducted in a manufactural environment with five participants, to investigate the effect of feedback on the energy consumption of the operator's machines. Due to the fact that the company, where this research was conducted, only had two machines available, only five machine operators were able to participate in the research experiment. Therefore, there was no possibility to acquire the necessary minimum amount of participants ($n \geq 34$). This was compensated by allowing the participants to complete many trials. In total, 457 trials were completed, which were analysed through the use of a Within-Participants Mixed Model design.

Working with a smaller amount of participants could cause difficulties to the data. Fortunately, all the participants have behaved in a rather similar way. Therefore, there was no reason to reject a participant (which represented 1/5th, or 20%, of the total result) as an outlier.

During the energy engagement experiment, stimuli materials obtained from the study I's survey were used. The objective, to reduce energy consumption through factual and social feedback, was significantly met and has thereby verified hypothesis H1: "Factual & Social Behaviour will make the participants behave in a more energy efficient way." Hence, by adding factual feedback to the milling machines, a total energy reduction of 2.9% was saved during production time, which equals an energy saving of 141.40 kWh and a reduction of 39.21 percent during non-productive times (e.g.

during lunch-breaks, weekends, and between shifts). Social feedback has accounted for a total energy reduction of 5.1% during production time, which equals a saving of 231.93 kWh and a 59.13 percent energy reduction during non-productive time, as can be read in chapter 3.3. However, because the machines were not able to be turned off, due to the chance of a cutting tool misalignment when restarting the machine, making comparisons between feedback and no feedback conditions where participants were able to turn off their machines, was not possible. The measured effect would therefore not be as much as indicated, if participants had been able to turn off their machines during both conditions. Despite the fact that we can argue that both feedback conditions do reduce the energy consumption considerably, in order to make a fair comparison and to fully understand the difference between no feedback and feedback conditions, this study should be replicated in which participants should be able to turn off their machines during both conditions.

The results were able to confirm our third hypothesis (H3): Less energy will be consumed by the machines when feedback is provided to the machine operators, than when operators receive no feedback at all. The hypothesis has confirmed the theory of saving 5-15% energy in industry, which was argued by DNV GL (2011) and Wising, et al. (2014). Our research experiment did not have a baseline condition. This baseline condition could have had participants who should have been able to have a pushbutton. Pressing this pushbutton could not have resulted in any type of feedback at all. This would have given us the opportunity to have made a fair comparison between all the conditions.

The CNC milling machines at Takumi Engineering Ltd. have consumed 2.1kW on average when running idle, and 5-10kW when running in production mode, depending on material hardness and size. This would mean an auxiliary electrical energy share of 21-42% of the total amount of energy. If the amount of auxiliary energy was as large as Dahmus and Gutowski have theorised (32-52%), savings would be considerably larger. Therefore, if the study at Takumi was conducted elsewhere, where the auxiliary energy share was as large as 32-52%, the energy savings impact would be considerably higher.

The results of this study also support our hypothesis (H2) that participants who have received social feedback, have reduced the machine’s idle time more often than participants who received factual feedback. Hence, the difference between both feedback conditions is 90.53 kWh. These results are in agreement with the research done by Ham and Midden (2008, 2009, 2014), who have suggested that using factual and social feedback is beneficial in improving energy efficiency, whereas social feedback has the highest potential of improving energy efficient behaviour.

Monetary savings have proven to be marginal for Takumi Precision Engineering Ltd. (€18.20 per month through the use of factual feedback and €32.02 per month through the use of social feedback) during production times. However, when considering the non-productive periods, such as lunch breaks, time between shifts and weekends, savings can reach €370.82 per month through the use of factual feedback, and €632.65 through the use of social feedback.

Considering this study was conducted in a small company (with only 5 milling machines in use), savings could considerably be enlarged if feedback systems were applied at a medium-sized or large manufactural company.

Besides reducing energy consumption, the total production time (which is the time between the production initiation time of one part until the production initiation time of the next part) has been greatly reduced as well. By adding feedback to the process, the total production time per product has been reduced by 7.9%. This allows the company to produce 13 parts in the same time they would normally produce 12 parts. Adding feedback could therefore be significantly beneficial, for increasing both the time and energy efficiency of the manufactural process, in industry.

Although the social feedback results are promising, the feedback itself could be improved. At displaying of the emoticons, we had been using the colour green for a happy face, yellow for a neutral face, and red for a sad face. However, results had been based on the emoticon’s facial expression only as if there had been no colour at all. The colour could therefore bias the persuasive power of social feedback compared to the persuasive power of factual feedback. We reason however that this extra stimulus (green/yellow/red colour) is rather small compared to the persuasive power of the facial expression; although this additional form of feedback should be taken into consideration when reviewing the outcome of social feedback versus factual feedback.

5.3 Study III: Post-experiment survey

Following the energy engagement experiment (study III), a survey had been distributed amongst the machine operators. Despite the positive results, the survey did not have an enough of a statistically significant power in order to be relevant to the research, most likely due to a small number of participants. Although, all five participants have enjoyed the feedback conditions and were keen on having their feedback attached to their machines in the future. They all believe that this feedback will most surely reduce the machine’s power consumption. Therefore, these questionnaire results should be treated as tentative information only.

5.4 Future research

Conducting this study in a real life manufactural environment, rather than in a controlled laboratory environment, is invaluable as a reality comparison, but it does limit the research in some way. In light of future research, the following limitations of this study might be taken into consideration, when continuing the research.

As our research was a field experiment, the environment was not fully adjustable and it was not fully suited to the experiment's needs, as one would have been in a lab experiment. Only two machines were available, and only, a small amount of machine operators were therefore available as participants. This has affected the research in some way, although the effect between participants had not been significant, nor had the effect of the two slightly different types of machines been significant. The effect of inter-personal differences would be larger with a small amount of participants than it would be with a larger group of participants. Ideally, it would have been better having been able to use one single type of machine and having had a large amount of participants.

Due to the delicate and high precision nature of the manufactural processes, the machines could not be turned off during the research experiment. This has been a major drawback, as it has limited the study to only two feedback conditions without the possibility of comparing the results to a control condition. Valuable conclusions could only be drawn between feedback conditions, rather than between feedback conditions and a control (base line) condition. In future research, a control condition should be made available, in order to investigate the effects of displaying, or not displaying feedback to machine operators.

In regard to the giving of social feedback (emoticons), it would have been more sensible to have used one single and preferably neutral colour for all emoticons, rather than using three different kind of colours as we have used in our study. The three different colours could have induced an unwanted cofounding variable.

Organising a research study in a manufactural environment and interacting with their human machine operators will surely validate this study as a reality comparison. However, this research has brought some minor challenges, due to the company's pre-defined environment and the number of available participants. In regard to a follow-up research, we would like to advise scientists to complete their research in a larger production area, with preferably a higher amount of machine operators in order to meet a larger quantity and a larger variety of participants and of machines. We would recommend improving statistical power through the use of many unique participants.

Another approach in reducing energy and costs would perhaps also be to use a different method of feedback. For example, a buzzer or the colours of a stack light. These items could be used in order to provide feedback instead using of a separate display, such as we have used in our research. These kinds of stack lights are widely available nowadays, and commonly present on a production machine, as has been illustrated in Figure 2.3. By pursuing this recommendation, a company might find it easier to cooperate with scientists, if the system being used is familiar already. The employees might not find new research as intrusive, but rather helpful to their production process, if they have already been accustomed to interacting with technology in a professional setting. This is what Human Technology Interaction should be all about. It is about paving the way for future implementation of feedback systems, by allowing humanity to keep interacting with technology and by granting technology the opportunity to try to become as smart as their human creators.

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APPENDICES

Appendix A Questionnaire 1

Questionnaire 1

This is the first part of the experiment. Please fill in this questionnaire, which contains only 16 questions and will take approximately 10 minutes of your time.

A line indicates a space to write at, a ☐indicates a ranking box, and a ○ indicates ticking the right box. Only one box can be ticked per question.
Please don't feel rushed. Take your time and read every question well.

1. **Please fill in your first and last name below.**

____

2. **What is the highest level of education/training, which you have completed to date?**

____

3. **How many years of experience do you have within a manufacturing environment?**

Less than 1	1-3	4-6	7-9	10 or more
○	○	○	○	○

4. **How many production machines do you operate at work a day?**

None	1	2	3	4 or more
○	○	○	○	○

5. **How many products do you on average make a day?**

None	1-5	6-20	21-50	51 or more
○	○	○	○	○

6. **Are you aware that some machines are running unnecessarily?**
(They could be turned off instead to save energy).

Yes	No
○	○

7. **Are you aware that machines use power even when they are in an idle state?**

Yes	No
○	○

8. **Do you know when your machine can be turned off?**

Yes	No
○	○

9. **Do you have the authority to do so?**

Yes	No
○	○

10. **If you know when to turn off a machine and have the authority, would you do this when it is possible to save on energy?**

Yes	No
○	○

The next section is about energy consumption feedback at your workplace. This kind of feedback will be displayed on a screen, attached to a machine that you operate. Below, some examples of feedback are given, which indicate whether you work in an energy inefficient way (by leaving the machine running when it produces nothing) or in an energy efficient way (by turning off the machine when it is not productive).

Traffic light design:

(red: being energy inefficient; green: being energy efficient)

Emoticon design:

(☹: being energy inefficient; ☺: being energy efficient)

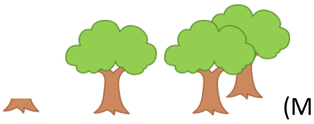
Male avatar design:

(☹: being energy inefficient; ☺: being energy efficient)

Female avatar design:

(☹: being energy inefficient; ☺: being energy efficient)

Growing trees design:



(More trees are raised when you are being more energy efficient)

Eco Score design:

(A higher score is obtained when you can being more energy efficient. Also extra flowers are added to the environmental picture)

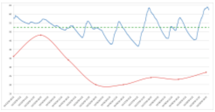
Gauge energy usage indicator:

(displays the amount of kWh used)

Digital energy usage indicator:

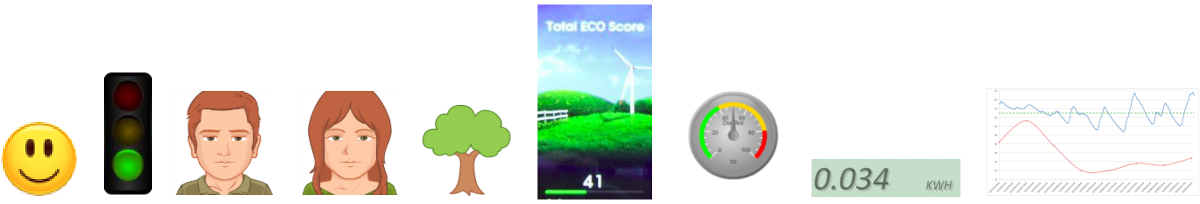
(displays the amount of kWh used)

Graphical energy usage indicator:



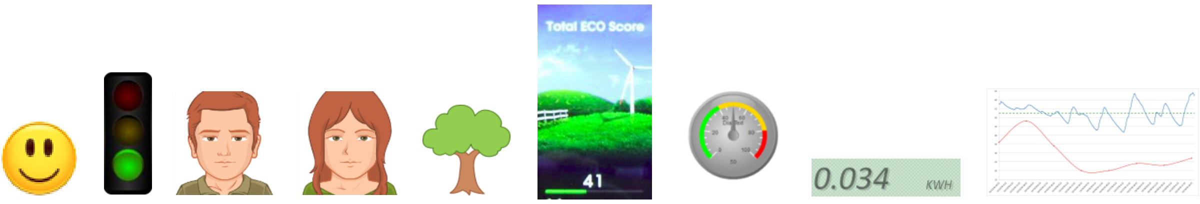
(displays the amount of kWh used over time)

11. Which type of feedback do you think will work best on the screen attached to the machine?
Please rank the following items from 1 (best) to 9 (worst).



☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

12. Which type of feedback do you prefer to have on your own screen attached to the machine?
Please rank the following items from 1 (most preferred) to 9 (least preferred).



☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

13. This type of feedback should be added to every machine in the production environment.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

14. The feedback method is a waste of time and money.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

15. I like this kind of feedback.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

16. The feedback will make the production environment more energy efficient.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

Appendix B Results questionnaire 1

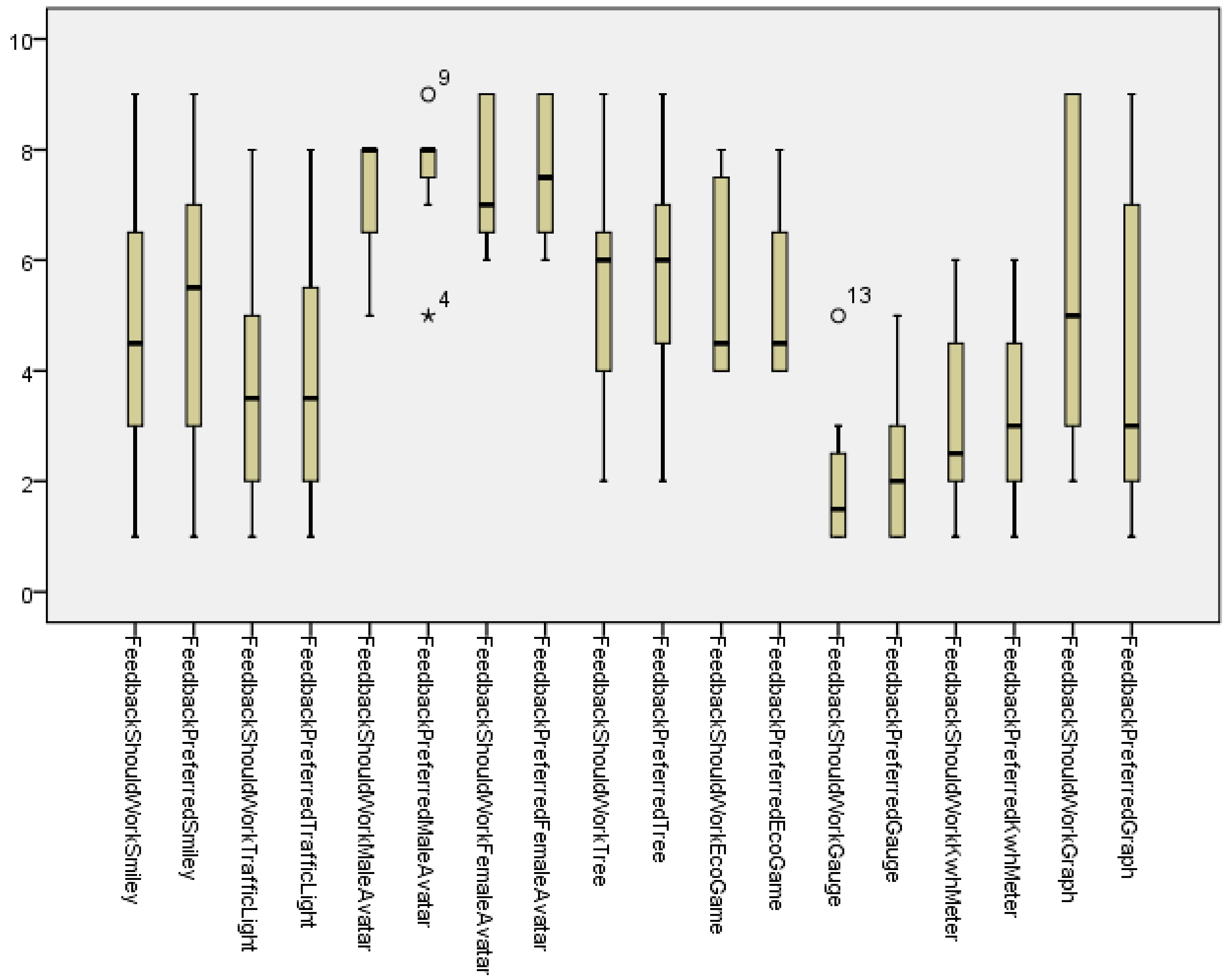


Figure B.1. Boxplot of ‘feedback should work estimate’ and ‘feedback preferred’. A low scale is the most preferred; a high scale is the least preferred.

Table B.1. The social feedback types are indicated in yellow, the factual feedback types are indicated in white.

	Feedback Should Work Emoticon	Feedback Should Work Traffic Light	Feedback Should Work Male Avatar	Feedback Should Work Female Avatar	Feedback Should Work Tree	Feedback Should Work Eco Game	Feedback Should Work Gauge
Mean	4.55	3.46	6.60	7.00	4.91	6.00	2.36
Median	4.00	3.00	7.50	7.00	5.00	6.00	2.00
Std. Deviation	2.734	2.665	2.221	2.108	2.300	2.000	1.629
Range	8	8	7	7	8	5	4
Minimum	1	1	1	2	1	4	1
Maximum	9	9	8	9	9	9	5

	Feedback Should Work Kwh Meter	Feedback Should Work Graph	Feedback Preferred Emoticon	Feedback Preferred Traffic Light	Feedback Preferred Male Avatar	Feedback Preferred Female Avatar	Feedback Preferred Tree
Mean	3.82	5.00	4.50	3.17	7.63	7.63	5.22
Median	4.00	3.00	4.50	3.00	8.00	7.50	6.00
Std. Deviation	1.888	2.864	2.759	2.250	1.188	1.302	2.539
Range	5	7	8	7	4	3	8
Minimum	1	2	1	1	5	6	1
Maximum	6	9	9	8	9	9	9

	Feedback Preferred Eco Game	Feedback Preferred Gauge	Feedback Preferred Kwh Meter	Feedback Preferred Graph	Should add to every machine?	Waste of time and money?	Like it?	Better energy efficiency?
Mean	5.25	2.10	3.60	4.20	2.07	4.07	1.93	1.93
Median	4.50	2.00	3.50	3.50	2.00	4.00	2.00	1.50
Std. Deviation	1.581	1.287	1.647	2.781	1.385	.997	.475	1.269
Range	4	4	5	8	4	4	2	4
Minimum	4	1	1	1	1	1	1	1
Maximum	8	5	6	9	5	5	3	5

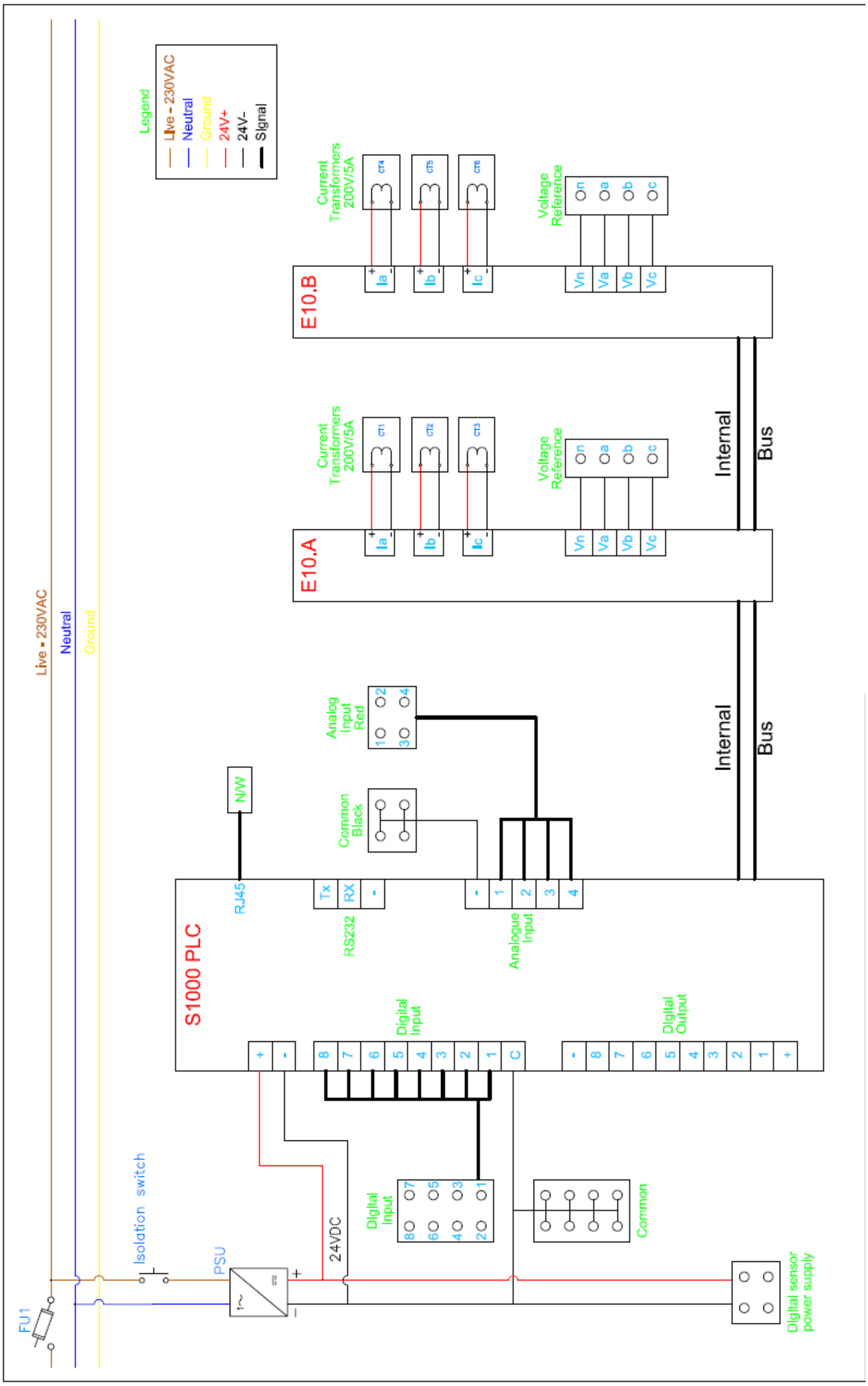
One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Aware turn off machine	8.832	13	.000	.857	.65	1.07
Aware power use	13.000	13	.000	.929	.77	1.08
Knowledge when turn off	7.416	11	.000	.833	.59	1.08
Authority to turn off	4.183	10	.002	.636	.30	.98
Would you turn off?	11.000	11	.000	.917	.73	1.10

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Aware turn off machine	17	0	1	.88	.332
Aware power use	17	0	1	.94	.243
Knowledge when turn off	15	0	1	.73	.458
Authority to turn off	14	0	1	.50	.519
Would you turn off?	15	0	1	.93	.258
Valid N (listwise)	14				

Appendix C Functional block diagram experiment set-up



Appendix D Participant's instructions

Dear machine operator,

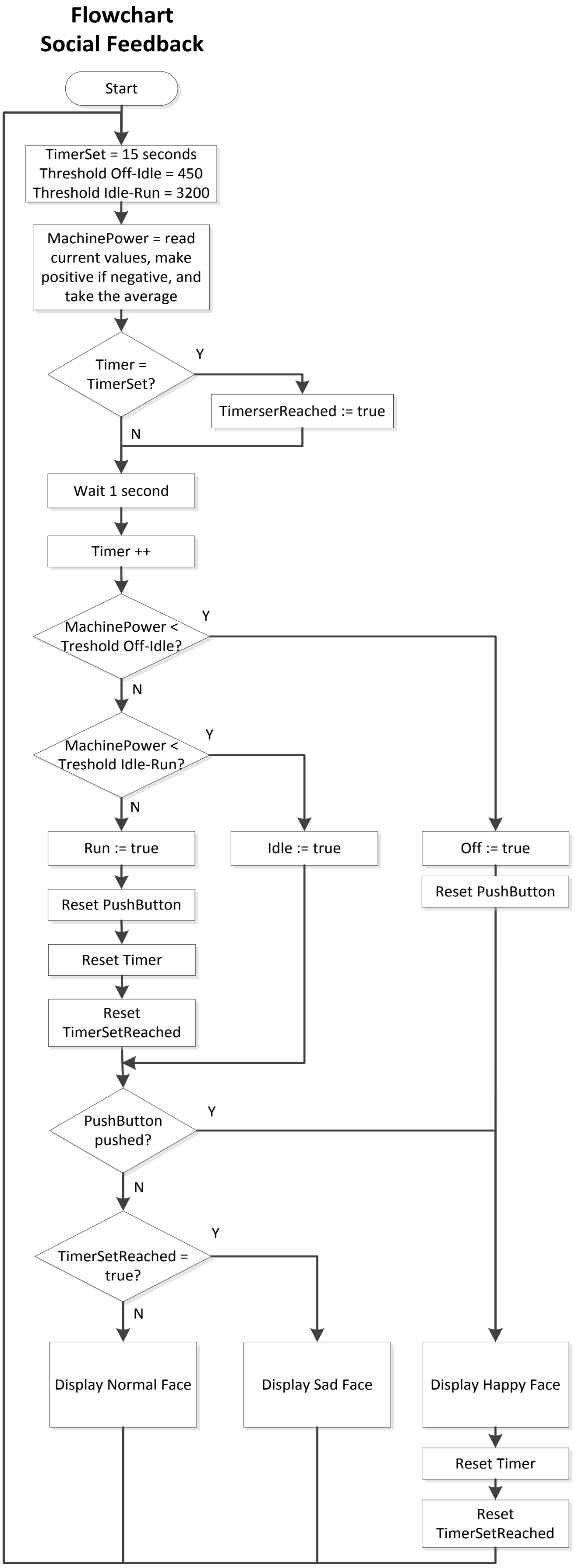
This new screen and this green button are a part of an 'Energy Efficiency Improvement Project' in order to identify when a machine is idle and still using energy. I know this machine can't be turned off, when it's running idle to save energy. But in order to gain valuable data we would kindly ask you to participate in this research.

Whenever you feel that it is suitable to switch off the machine (for example: after a product is finished, or at the end of a shift), please press the green button. The green button does not interfere with the production process; it is just a simulated button in order to record your decision to switch the machine into energy saving mode. Feedback is provided by the screen next to the machine.

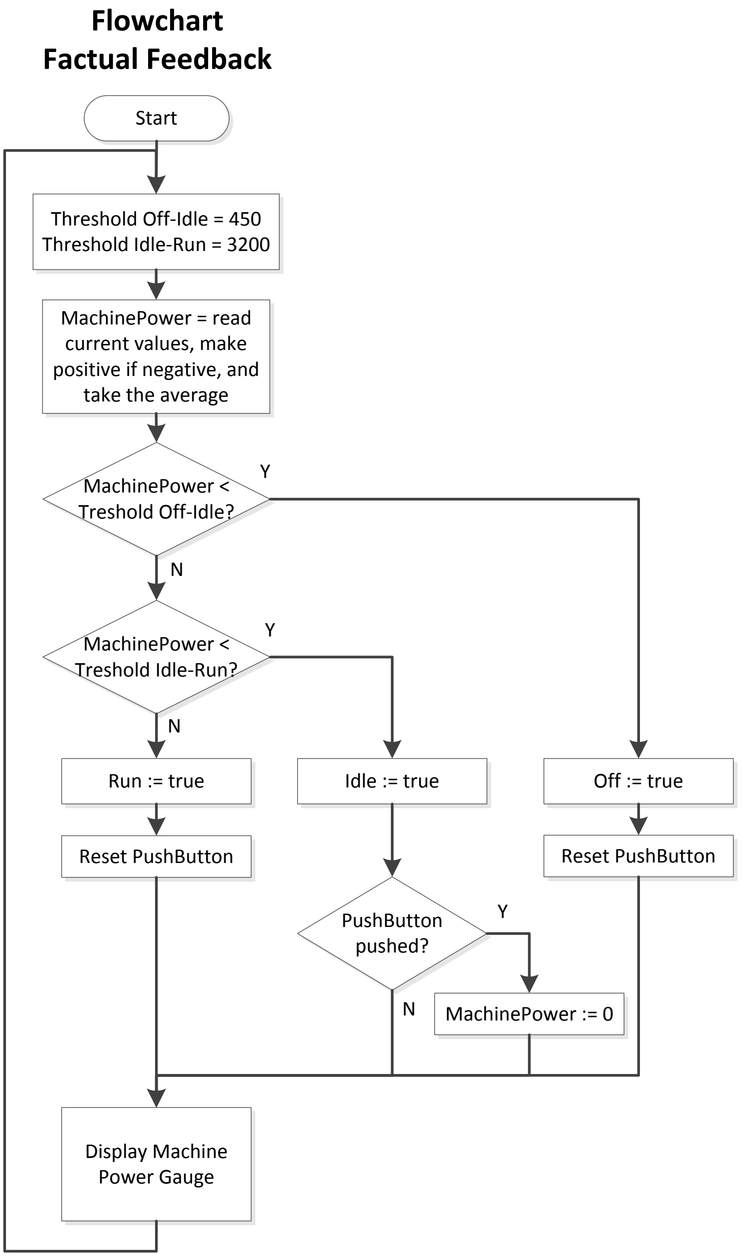
Thank you very much for your cooperation. Your input is highly appreciated!

- The energy savings team.

Appendix E Flowchart social feedback



Appendix F Flowchart factual feedback



Appendix G PLC Program Code: Global Variables

```
VAR_GLOBAL


(* Input variables *)
        DoorClosed :        BOOL;     (* Machine door sensor *)
        PushButton :        INT;      (* PushButton to simulate to turn off machine *)
        PowerL1 :           INT;      (* Power from current transformer L1 *)
        PowerL2 :           INT;      (* Power from current transformer L2 *)
        PowerL3 :           INT;      (* Power from current transformer L3 *)

(* Calculation variables *)
        Timer :             DINT;     (* timer count value (DINT = up to 4 bytes = ~1 year *)
         TimerIdle :        DINT;
        MachinePower :      INT;      (* Machine Power Used *)

(* setting variables *)
        TreshIdleOff :      INT;      (* Power threshold between machine idle & off state *)
        TreshRunIdle :      INT;      (* Power threshold between machine running & idle state *)
        Timerset :          INT;      (* timer setting *)

(* Output variables *)
        Off :               BOOL;     (* Machine is in off state *)
        Idle :              BOOL;     (* Machine is in idle state *)
        Run :               BOOL;     (* Machine is in running state *)
        TimersetReached :   BOOL;     (* timer counter value has reached "Timerset" value *)
        DisappearHappy :    BOOL;     (* Toggle Shape *)
        DisappearNormal :   BOOL;     (* Toggle Shape *)
        DisappearSad :      BOOL;     (* Toggle Shape *)

END_VAR
```

Appendix H PLC Program Code: social feedback (Miyano CNC machine)

```
PROGRAM Social_Feedback


(***********************************)
(* Predefined variables *)
 Timerset     :=  150;                (* Amount of 0.1seconds delay timer setting. 150 = 15 seconds delay timer *)
 TreshIdleOff :=  450;                (* Power threshold between machine idle & off state *)
 TreshRunIdle := 3200;                (* Power threshold between machine running & idle state *)
 (***********************************)

(* make absolut current transformer values (in case one is connected in the wrong direction) *)
 IF AVA_0 < 0.0 THEN
  PowerL1 := -1 * AVA_0;
 ELSE
  PowerL1 := AVA_0;
 END_IF;
 IF BVA_0 < 0.0 THEN
  PowerL2 := -1 * BVA_0;
 ELSE
  PowerL2 := BVA_0;
 END_IF;
 IF CVA_0 < 0.0 THEN
  PowerL3 := -1 * CVA_0;
 ELSE
  PowerL3 := CVA_0;
 END_IF;

(* machine power calculations *)
 MachinePower := PowerL1+PowerL2+PowerL3;

 (* timer counter *)
 IF Timer >= Timerset THEN
  TimersetReached := TRUE;
 END_IF;
 WAIT(100);                              (* wait for 0.1 second *)
 Timer := Timer + 1;                     (* increase Timer with 0.1 second *)

(* Is the machine loading door open or closed? *)
 IF din1 = TRUE THEN
  DoorClosed := TRUE;
 ELSE
  DoorClosed := FALSE;
 END_IF;

(* PushButton (din3) activation *)
 IF din3 = TRUE THEN                     (* When the push button is pushed, then machine shut down is simulated *)
  PushButton := 1;
 END_IF;

 (* Display output on screen *)
 IF PushButton = 1 THEN
  DisappearHappy   := FALSE;             (* Display Happy face *)
  DisappearNormal  := TRUE;
  DisappearSad     := TRUE;
  Timer := 0;                            (* timer reset *)
  TimersetReached  := FALSE;             (* timer reset *)
 ELSIF TimersetReached = TRUE THEN
  DisappearHappy   := TRUE;
  DisappearNormal  := TRUE;
  DisappearSad     := FALSE;             (* Display Sad face *)
 ELSE
  DisappearHappy   := TRUE;
  DisappearNormal  := FALSE;             (* Display Normal face *)
  DisappearSad     := TRUE;
 END_IF;

 (* machine is in running/idle/off state? *)
 IF MachinePower < TreshIdleOff THEN     (* machine is in off state *)
  Off  := TRUE;                          (* used for logging purposes only *)
```

```
   Idle := FALSE;                        (* used for logging purposes only *)
   Run  := FALSE;                        (* used for logging purposes only *)
   DisappearHappy   := FALSE;            (* Display Happy face *)
   DisappearNormal  := TRUE;
   DisappearSad     := TRUE;
   Timer := 0;                           (* timer reset *)
            TimersetReached  := FALSE;   (* timer reset *)
   PushButton := 0;                      (* Reset pushButton function to 0 *)
  ELSIF MachinePower < TreshRunIdle THEN (* machine is in idle state *)
            Off  := FALSE;               (* used for logging purposes only *)
            Idle := TRUE;                (* used for logging purposes only *)
            Run  := FALSE;               (* used for logging purposes only *)
            TimerIdle := TimerIdle + 1;  (* log the amount of time the machine is running idle *)
  ELSE                                   (* machine is in running state *)
            Off  := FALSE;               (* used for logging purposes only *)
            Idle := FALSE;               (* used for logging purposes only *)
            Run  := TRUE;                (* used for logging purposes only *)
   PushButton := 0;                      (* Reset pushButton function to 0 *)
            Timer := 0;                  (* timer reset *)
   TimersetReached := FALSE;             (* timer reset *)
  END_IF;

  (* Data Logging *)
  IF DoorClosed = TRUE THEN
   do1 := TRUE;
  ELSE
   do1 := FALSE;
  END_IF;
  IF PushButton = 1 THEN
   do2 := TRUE;
  ELSE
   do2 := FALSE;
  END_IF;
  IF Off = TRUE THEN
   do3 := TRUE;
  ELSE
   do3 := FALSE;
  END_IF;
  IF Idle = TRUE THEN
   do4 := TRUE;
  ELSE
   do4 := FALSE;
  END_IF;
  IF Run = TRUE THEN
   do5 := TRUE;
  ELSE
   do5 := FALSE;
  END_IF;
  IF DisappearHappy = FALSE THEN
   do6 := TRUE;
  ELSE
   do6 := FALSE;
  END_IF;
  IF DisappearNormal = FALSE THEN
   do7 := TRUE;
  ELSE
   do7 := FALSE;
  END_IF;
  IF DisappearSad = FALSE THEN
   do8 := TRUE;
  ELSE
   do8 := FALSE;
  END_IF;

END_PROGRAM
```

Appendix I PLC Program Code: factual feedback (Miyano CNC machine)

```
PROGRAM Factual_Feedback


(***********************************)
(* Predefined variables *)
 TreshIdleOff :=  450;                  (* Power threshold between machine idle & off state *)
 TreshRunIdle := 3200;                  (* Power threshold between machine running & idle state *)
 (***********************************)

 (* make absolut current transformer values (in case one is connected in the wrong direction) *)
 IF AVA_0 < 0.0 THEN
   PowerL1 := -1 * AVA_0;
 ELSE
   PowerL1 := AVA_0;
 END_IF;
 IF BVA_0 < 0.0 THEN
   PowerL2 := -1 * BVA_0;
 ELSE
   PowerL2 := BVA_0;
 END_IF;
 IF CVA_0 < 0.0 THEN
   PowerL3 := -1 * CVA_0;
 ELSE
   PowerL3 := CVA_0;
 END_IF;

 (* machine power calculations *)
 MachinePower := PowerL1+PowerL2+PowerL3;

 (* Is the machine loading door open or closed? *)
 IF din1 = TRUE THEN
   DoorClosed := TRUE;
 ELSE
   DoorClosed := FALSE;
 END_IF;

 (* PushButton (din3) activation *)
 IF din3 = TRUE THEN (* When the push button is pushed, then machine shut down is simulated *)
   PushButton := 1;
 END_IF;

 (* machine is in running/idle/off state? *)
 IF MachinePower < TreshIdleOff THEN       (* machine is in off state *)
   Off  := TRUE;                           (* used for logging purposes only *)
   Idle := FALSE;                          (* used for logging purposes only *)
   Run  := FALSE;                          (* used for logging purposes only *)
   PushButton := 0;                        (* Reset pushButton function to 0 *)
 ELSIF MachinePower < TreshRunIdle THEN (* machine is in idle state *)
   Off  := FALSE;                          (* used for logging purposes only *)
   Idle := TRUE;                           (* used for logging purposes only *)
   Run  := FALSE;                          (* used for logging purposes only *)
   IF PushButton = 1 THEN
     MachinePower := 0;                    (* Machine Power Gauge will display 0 watt *)
     Off  := TRUE;                         (* used for logging purposes only *)
     Idle := FALSE;                        (* used for logging purposes only *)
     Run  := FALSE;                        (* used for logging purposes only *)
   END_IF;
 ELSE (* machine is in running state *)
   Off  := FALSE;                          (* used for logging purposes only *)
   Idle := FALSE;                          (* used for logging purposes only *)
   Run  := TRUE;                           (* used for logging purposes only *)
   PushButton := 0;                        (* Reset pushButton function to 0 *)
 END_IF;

 (* Data Logging *)
 IF DoorClosed = TRUE THEN
   do1 := TRUE;
 ELSE
   do1 := FALSE;
```

```
  END_IF;
  IF PushButton = 1 THEN
    do2 := TRUE;
  ELSE
    do2 := FALSE;
  END_IF;
  IF Off = TRUE THEN
    do3 := TRUE;
  ELSE
    do3 := FALSE;
  END_IF;
  IF Idle = TRUE THEN
    do4 := TRUE;
  ELSE
    do4 := FALSE;
  END_IF;
  IF Run = TRUE THEN
    do5 := TRUE;
  ELSE
    do5 := FALSE;
  END_IF;

END_PROGRAM
```

Appendix J Results Study II (Energy Saved in kWh and %)

```
MIXED PowerSaved BY Condition
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1)
SINGULAR(0.000000000001) HCONVERGE(0,
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Condition | SSTYPE(3)
  /METHOD=REML
  /PRINT=DESCRIPTIVES SOLUTION
  /RANDOM=INTERCEPT | SUBJECT(ppn) COVTYPE(VC)
  /EMMEANS=TABLES(Condition) .
```

Mixed Model Analysis

Case Processing Summary

		Count	Marginal Percentage
Operator (ppn)	1	159	34.8%
	2	41	9.0%
	3	164	35.9%
	4	32	7.0%
	5	61	13.3%
Condition (FF/SF)	FF	227	49.7%
	SF	230	50.3%
Valid		457	100.0%
Excluded		0	
Total		457	

Descriptive Statistics

Power Saved (Off-state consumption) (Watt)

Operator (ppn)	Condition (FF/SF)	Count	Mean	Standard Deviation	Coefficient of Variation
1	Factual Feedback	77	66.70	113.948	170.8%
	Social Feedback	82	106.60	176.144	165.2%
	Total	159	87.27	150.173	172.1%
2	Factual Feedback	28	65.11	106.730	163.9%
	Social Feedback	13	118.79	250.411	210.8%
	Total	41	82.13	164.743	200.6%
3	Factual Feedback	82	64.48	116.063	180.0%
	Social Feedback	82	114.42	217.751	190.3%
	Total	164	89.45	175.737	196.5%
4	Factual Feedback	10	20.26	64.058	316.2%
	Social Feedback	22	545.73	641.930	117.6%
	Total	32	381.52	584.443	153.2%
5	Factual Feedback	30	235.95	380.464	161.2%
	Social Feedback	31	381.59	447.775	117.3%
	Total	61	309.96	419.052	135.2%
Total	Factual Feedback	227	86.02	181.157	210.6%
	Social Feedback	230	189.14	342.106	180.9%
	Total	457	137.92	278.754	202.1%

Information Criteria[a]

-2 Restricted Log Likelihood	6365.581
Akaike's Information Criterion (AIC)	6369.581
Hurvich and Tsai's Criterion (AICC)	6369.607
Bozdogan's Criterion (CAIC)	6379.821
Schwarz's Bayesian Criterion (BIC)	6377.821

The information criteria are displayed in smaller-is-better forms.

a. Dependent Variable: Power Saved (Off-state consumption) (Watt).

Fixed Effects

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	3.882	9.669	.037
Condition	1	452.607	13.827	.000

a. Dependent Variable: Power Saved (Off-state consumption) (Watt).

Estimates of Fixed Effects[a]

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept	231.927851	61.227382	4.202	3.788	.018	65.106213	398.749490
[Condition=FF]	-90.529908	24.345761	452.607	-3.719	.000	-138.374664	-42.685152
[Condition=SF]	0[b]	0	.	.	.	.	.[b]

a. Dependent Variable: Power Saved (Off-state consumption) (Watt).

b. This parameter is set to zero because it is redundant.

Covariance Parameters

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error
Residual		66356.326767	4419.355158
Intercept [subject = ppn]	Variance	16921.057734	12915.551239

a. Dependent Variable: Power Saved (Off-state consumption) (Watts).

Estimated Marginal Means

Condition (FF/SF)[a]

Condition (FF/SF)	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
Factual Feedback	141.398	61.275	4.213	-25.390	308.186
Social Feedback	231.928	61.227	4.202	65.106	398.749

a. Dependent Variable: Power Saved (Off-state consumption) (Watts).

*-----PowerSavedPercentage (%)

```
MIXED PowerSavedPercentage BY Condition
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1)
SINGULAR(0.000000000001) HCONVERGE(0,
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Condition | SSTYPE(3)
  /METHOD=REML
  /PRINT=DESCRIPTIVES SOLUTION
  /RANDOM=INTERCEPT | SUBJECT(ppn) COVTYPE(VC)
  /EMMEANS=TABLES(Condition) .
```

Mixed Model Analysis

Case Processing Summary

		Count	Marginal Percentage
Operator (ppn)	1	159	34.8%
	2	41	9.0%
	3	164	35.9%
	4	32	7.0%
	5	61	13.3%
Condition (FF/SF)	FF	227	49.7%
	SF	230	50.3%
Valid		457	100.0%
Excluded		0	
Total		457	

Descriptive Statistics

% Power Saved

Operator (ppn)	Condition (FF/SF)	Count	Mean	Standard Deviation	Coefficient of Variation
1	Factual Feedback	77	.0261	.04332	166.0%
	Social Feedback	82	.0430	.06535	151.9%
	Total	159	.0348	.05625	161.6%
2	Factual Feedback	28	.0206	.03339	161.7%
	Social Feedback	13	.0131	.01963	149.5%
	Total	41	.0183	.02967	162.5%
3	Factual Feedback	82	.0249	.04153	167.0%
	Social Feedback	82	.0372	.05542	149.1%
	Total	164	.0310	.04921	158.7%
4	Factual Feedback	10	.0027	.00841	316.2%
	Social Feedback	22	.0956	.10222	107.0%
	Total	32	.0665	.09494	142.7%
5	Factual Feedback	30	.0337	.04620	137.2%
	Social Feedback	31	.0738	.08224	111.4%
	Total	61	.0541	.06945	128.4%
Total	Factual Feedback	227	.0249	.04116	165.0%
	Social Feedback	230	.0484	.06992	144.4%
	Total	457	.0368	.05859	159.4%

Information Criteria[a]

-2 Restricted Log Likelihood	-1303.109
Akaike's Information Criterion (AIC)	-1299.109
Hurvich and Tsai's Criterion (AICC)	-1299.083
Bozdogan's Criterion (CAIC)	-1288.869
Schwarz's Bayesian Criterion (BIC)	-1290.869

The information criteria are displayed in smaller-is-better forms.

a. Dependent Variable: % Power Saved.

Fixed Effects

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	3.185	34.268	.008
Condition	1	454.601	16.817	.000

a. Dependent Variable: % Power Saved.

Estimates of Fixed Effects[a]

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept	.050899	.007321	4.223	6.953	.002	.030989	.070809
[Condition=FF]	-.021920	.005345	454.601	-4.101	.000	-.032424	-.011415
[Condition=SF]	0[b]	0	.	.	.	.	.[b]

a. Dependent Variable: % Power Saved.

b. This parameter is set to zero because it is redundant.

Covariance Parameters

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error
Residual		.003215	.000214
Intercept [subject = ppn]	Variance	.000183	.000181

a. Dependent Variable: % Power Saved.

Estimated Marginal Means

Condition (FF/SF)[a]

Condition (FF/SF)	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
Factual Feedback	.029	.007	4.238	.009	.049
Social Feedback	.051	.007	4.223	.031	.071

a. Dependent Variable: % Power Saved.

Appendix K Results Study II (Machine type analysis)

```
*----PowerSaved(%) per non-productive power(%)

MIXED Off.Power_per_non.productive.Power BY MachineNumber
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1)
SINGULAR(0.000000000001) HCONVERGE(0,
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=MachineNumber | SSTYPE(3)
  /METHOD=REML
  /PRINT=DESCRIPTIVES
  /RANDOM=INTERCEPT | SUBJECT(ppn) COVTYPE(VC)
  /RANDOM=MachineNumber | SUBJECT(ppn) COVTYPE(VC).
```

Mixed Model Analysis

Descriptive Statistics

Off.Power_per_non.productive.Power

Operator (ppn)	Machine	Count	Mean	Standard Deviation	Coefficient of Variation
1	Miyano	159	.2957	.36083	122.0%
2	Miyano	40	.2816	.39393	139.9%
3	Miyano	163	.2938	.36898	125.6%
4	Doosan	32	.2929	.37093	126.6%
5	Doosan	61	.3144	.37315	118.7%
Total	Miyano	362	.2933	.36724	125.2%
	Doosan	93	.3070	.37051	120.7%
	Total	455	.2961	.36754	124.1%

Information Criteria[a]

-2 Restricted Log Likelihood	390.043
Akaike's Information Criterion (AIC)	396.043
Hurvich and Tsai's Criterion (AICC)	396.096
Bozdogan's Criterion (CAIC)	411.390
Schwarz's Bayesian Criterion (BIC)	408.390

Fixed Effects

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	453.000	196.996	.000
MachineNumber	1	453.000	.104	.747

a. Dependent Variable: Off.Power_per_non.productive.Power.

Covariance Parameters

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error
Residual		.135353	.008994
Intercept [subject = ppn]	Variance	.000000[b]	.000000
MachineNumber [subject = ppn]	Variance	.000000[b]	.000000

a. Dependent Variable: Off.Power_per_non.productive.Power.

b. This covariance parameter is redundant.

Appendix L Questionnaire 2

Post-research Questionnaire

Please fill in this questionnaire, which contains 30 questions and will take approximately 5 minutes of your time. Please don't feel rushed. Take your time to read every question properly.

Part 1 - General questions

1. **In general, I have enjoyed the way the feedback had been given.**

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

2. **The feedback had been distracting me from my work.**

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

3. **The feedback will make the production environment more energy efficient.**

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

4. **I feel a sense of satisfaction after turning off the machine (pushing the button).**

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

5. **I feel bad when I forget to turn off the machine.**

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

6. **When I did not turn off the machine, my colleague told me to turn off the machine.**

Yes, always	Yes, sometimes he did	No, never happened	No opinion
○	○	○	○

7. **After a product has been finished I want to turn off the machine, even without receiving the feedback.**

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

Part 2 – Social feedback related questions

8. I have liked the social feedback (smiley faces).

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

9. When the red smiley appears, I

Like it Very much	Like it	No opinion	Dislike it	Strongly Dislike it
○	○	○	○	○

10. When the green smiley appears, I

Like it Very much	Like it	No opinion	Dislike it	Strongly Dislike it
○	○	○	○	○

11. The social feedback (Smiley faces) had been easy to understand.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

12. The social feedback (Smiley faces) had been accurate.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

13. The social feedback (Smiley faces) annoyed me.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

14. The social feedback (Smiley faces) have increased my work motivation.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

15. The social feedback (Smiley faces) has helped me to make more products a day.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

16. Thanks to the social feedback (Smiley faces), I have worked in a more energy efficient way.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

17. The red smiley reminds me to turn off the machine.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

18. Most of the time I have been given the red smiley as a reminder to turn off the machine.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

19. I wish I could keep this social feedback (Smiley faces) at work from now on.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

Part 3 – Factual feedback related questions

20. I have liked the factual feedback (power gauge).

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

21. The factual feedback (power gauge) has been easy to understand.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

22. The factual feedback (power gauge) has been accurate.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

23. The factual feedback (power gauge) annoyed me.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

24. The factual feedback (power gauge) has increased my work motivation.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

25. The factual feedback (power gauge) has helped me to make more products a day.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

26. Thanks to the factual feedback (power gauge), I have worked in a more energy efficient way.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

27. I wish I could keep this factual feedback (power gauge) at work from now on.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

Part 4 – Your comments

28. I prefer another kind of feedback to have instead of the smiley face or power gauge.

Strongly Agree	Agree	No opinion	Disagree	Strongly Disagree
○	○	○	○	○

29. If you have a proposal, please describe your preferred form of feedback:

____

____

____

30. Do you have any comments regarding the feedback, the experiment, or anything else?

____

____

____

Please hand in this questionnaire to me, [NAME], or send a scan to [EMAIL]

Thank you for your cooperation. Your input and effort is highly appreciated!

- The TEMPO team of ACRON research centre, Limerick Institute of Technology.

Appendix M Results questionnaire 2

ppn	Age	Machine	Shift	In general, I have enjoyed the way the feedback had been given. 1	The feedback had been distracting me from my work. 2	The feedback will make the production environment more energy efficient. 3	I feel a sense of satisfaction after turning off the machine (pushing the button). 4	I feel bad when I forget to turn off the machine. 5	When I did not turn off the machine, my colleague told me to turn off the machine. 6	After a product has been finished I want to turn off the machine, even without receiving the feedback 7	I have liked the social feedback (smiley faces). 8	When the red smiley appears, I 9	When the green smiley appears, I 10	The social feedback (Smiley faces) had been easy to understand. 11	The social feedback (Smiley faces) had been accurate. 12	The social feedback (Smiley faces) annoyed me. 13	The social feedback (Smiley faces) have increased my work motivation. 14	The social feedback (Smiley faces) has helped me to make more products a day. 15	Thanks to the social feedback (Smiley faces), I have worked in a more energy efficient way. 16	The red smiley reminds me to turn off the machine. 17	Most of the time I have been given the red smiley as a reminder to turn off the machine. 18	I wish I could keep this social feedback (Smiley faces) at work from now on. 19	I have liked the factual feedback (power gauge). 20	The factual feedback (power gauge) has been easy to understand. 21	The factual feedback (power gauge) has been accurate. 22	The factual feedback (power gauge) annoyed me. 23	The factual feedback (power gauge) has increased my work motivation. 24	The factual feedback (power gauge) has helped me to make more products a day. 25	Thanks to the factual feedback (power gauge), I have worked in a more energy efficient way. 26	I wish I could keep this factual feedback (power gauge) at work from now on. 27	I'd prefer another kind of feedback to have instead of the smiley face or power gauge. 28	If you have a proposal, please describe your preferred form of feedback: 29	Do you have any comments regarding the feedback, the experiment, or anything else? 30
1	35	Miyano	Day	2	4	2	2	2	2	3	2	4	2	2	2	2	3	3	2	2	2	2	2	2	2	4	2	3	2	2	2		
2	31	Miyano	Day	1	4	1	2	2	2	2	1	3	2	1	2	5	3	2	2	2	1	2	2	2	2	4	2	2	2	2	4	-	-
3	46	Miyano	Night	2	4	1	2	2	4	3	2	4	2	2	2	4	3	3	3	2	2	2	2	2	2	4	3	3	3	2	2	Beeper, or some kind of siren	
4	41	Doosan	Day	3	3	3	2	2	3	3	2	4	2	2	1	4	3	3	2	2	2	3	3	2	3	3	3	3	3	3	3		
5	27	Doosan	Night	2	3	2	3	3	2	2	2	3	3	1	2	4	3	4	4	2	2	3	2	2	2	4	3	4	4	3	3	-->	It's easy to forget to press the button, Is it possible to have the computer/gauge go into 0 power/off mode automatically after the machine goes idle?
			Average:	2,0	3,5	1,8	2,3	2,3	2,8	2,5	1,8	3,5	2,3	1,5	1,8	4,3	3,0	3,0	2,8	2,0	1,8	2,5	2,3	2,0	2,3	3,8	2,8	3,0	3,0	2,5	3,0		

xcept for questions 6, 9, and 10:

1	*= Stronly Agree*
2	*= Agree*
3	*= No opinion*
4	*= Disagree*
5	*= Stronly Disagree*

1 = Like it very much
2 = Like it
3 = No opinion
4 = Dislike it
5 = Strongly dislike it

1 = Yes, always
2 = Yes, sometimes he did
3 = No, never happened
4 = No opinion