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5.5 Energy efficiency in production processes – the influence of consumption visualization and staff training

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Abstract
This paper examines the influence of the visualization of consumed compressed air and staff training on the consumption behavior of employees in a real production process. To measure potential changes in consumption behavior a real-effort experiment at the Training Factory for Energy Productivity, a real production setting at *iwb* of TUM, had been designed. Therefore, four groups were defined, each group in a different experimental setting. This experiment is the first one ever conducted in a real-life setting and thus adds valuable results to academia and practitioners. Compared to the group without any information about the amount of consumed compressed air the participants provided with a display showing this information saved on average 7-8%. The group provided with a movie about general measures to save compressed air in production consumed around 24% less compressed air than all other groups of participants. Generally, no significant differences between male and female participants had been found.

Keywords:
Empirical study, employee behavior, energy efficiency, production, sustainable manufacturing

1 INTRODUCTION

Today's manufacturing companies are faced with the need to reduce energy consumption sustainably [1]. Growing energy prices [2] due to the increasing demand for energy are only one reason. Moreover, in companies large energy saving potentials that allow for increasing energy efficiency still exist [3, 4].

In order to sensitize people for energy efficiency and show possibilities to reduce energy consumption the Training Factory for Energy Productivity (Lernfabrik für Energieproduktivität, LEP) was built up at *iwb* (Institute for Machine Tools and Industrial Management, see figure 1) [5].

Figure 1: Training Factory for Energy Productivity.

At LEP a small gearbox is manufactured. Therefore, the shaft is turned, the main gear hardened by heating and quenching and finally the gearbox assembled. To display the manufacturing process machines of different ages, automatic as well as manual processes and different forms of energy (steam, electricity, thermal energy and compressed air) are used.

During a sensitization training at LEP participants from all hierarchical levels learn and practically apply a methodological approach that can directly be utilized in real production environments, the Energy Value Stream (EVS) [6]. EVS mainly consists of two phases: the analysis and the design phase (see figure 2).

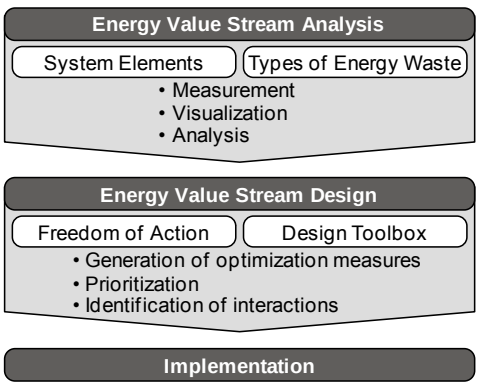

Figure 2: Energy Value Stream (EVS).

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EVS was deduced from the methodology value stream mapping from Lean Management [7]. During the analysis phase energy waste is identified by measuring energy consumption in a defined area, visualizing the values and applying various analysis methods. Thereby, the three system elements (technology & system, organization & management, human & behavior [8]) and different types of energy waste (overproduction, dead time, transport, inventory, rejections, movements, unused potential of employees) have to be considered. The design phase aims at limiting energy waste. For this purpose the freedoms of action have to be defined and optimization measures generated by applying a design toolbox. Then measures are prioritized regarding their complexity and cost effectiveness. After choosing the right measures, they have to be implemented.

When optimizing production technological systems the three already mentioned system elements need to be considered. Since numerous works in the fields of the first two elements were already carried out [9] this article focuses on human & behavior. Furthermore, workers in production have due to their behavior a large influence on energy consumption. Therefore, a study was carried out to analyze their influence. For this purpose a process step at LEP was chosen where workers' behavior affects energy consumption. Hence, the final assembly station was picked. Here, the gear box is screwed pneumatically by 6 bolts. Another reason for choosing this process was the use of compressed air, as the economical application of compressed air is crucial due to its poor degree of efficiency. The worker can influence the consumption of compressed air by setting the pressure at the workplace.

The findings of the study will be presented in the following chapters. It was conducted in an interdisciplinary team consisting of engineers and behavioral economists.

2 STATE OF THE ART

Even though the public discussion about resource efficiency, environmental issues and climate protection increased tremendously over the past years [10] only a few studies on energy efficient measures in the work-place context have been conducted so far [11]. One of the few studies in that field is the work of Siero et. al. about the influence of goal-setting, feedback and education on employees' behaviour [12]. They figured out that among other things creating awareness for the topic of energy efficiency as well as goal-directed education and feedback lead to significant behaviour changes of the workforce resulting in less energy-wasting.

In order to enhance the available findings on how to increase resource efficiency in the work place established concepts from the field of behavioural economics should be applied [13, 14]. Therefore, this study will put strong emphasize on the feedback mechanism consumption visualization and staff training also as potential measures to increase energy efficiency in production processes.

3 SETUP OF THE STUDY

The experiment took place at LEP in November and December 2012. In total 160 students took part in the study and were randomly distributed to the four different conditions of the experiment. The experiment took between 45 and 60 minutes for each participant and they were remunerated with a fixed payment of 8 euros. In each experimental group consisting of 40 students 13 had been female and the other 27 male. Therefore, an equal gender distribution over the groups is guaranteed. The general experimental setting can be seen in figure 3.

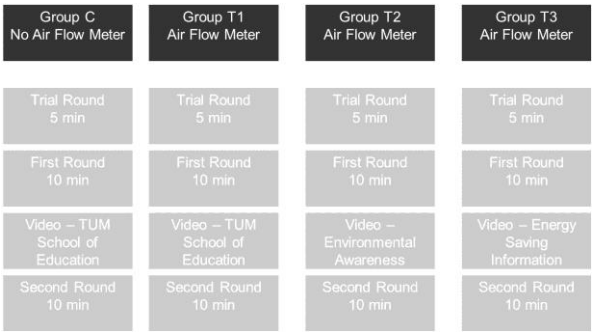

Figure 3: Experimental setting.

Before the experiment started participants were introduced to the work station by a power point presentation and a video to ensure a standardized procedure for every participant. Following, all participants got a five minutes lasting trial round to get familiar with the work place setting and the task. After a short break with additional information people started with the first round which took 10 minutes. Depending on the group the students belonged to a certain movie was shown to them which had duration of around five minutes. Group C and T1 saw a movie about a new faculty at Technische Universitaet Muenchen (TUM), the TUM School of Education. The movie had no relation to the task, the environment or energy saving information. Group T2 got a movie showing nature scenes to address the environmental awareness of the participants. To group T3 a movie was shown which gave particular information on how to reduce consumption of compressed air in production. After the movie participants did execute the second round of the experiment for ten minutes. The last step of the procedure was a questionnaire which had to be filled in by all participants.

As it can be seen in figure 3 groups T1, T2 and T3 had an air flow meter next to them on the work station during the whole duration of the experiment. Therefore, they were able to get continuous information about their cumulated consumption of compressed air.

After each of the three rounds the experimenter counted the finished and unfinished gear boxes the participant performed. This number was after the experiment compared to the used amount of compressed air by each round to calculate the exact number of litres of compressed air per screwed bolt (l/bolt).

4 RESULTS

4.1 Differences between experiment rounds and treatment

First of all the influence of visualizing consumption of compressed air on participants' behavior is shown. To isolate the effect of the display on the consumption only the results of the trial round and the first round are taken into

consideration since besides the display's appearance for groups T1 – T3 and non-appearance for the control group everything is equal over all four groups in these two rounds. As it can be seen in table 1 where the results are ordered by the experiment sequence in the trial round group C uses on average 10.76 l/bolt and the treatment groups between 9.87 and 10.18 l/bolt. This results in a saving between 5.4% and 8.3% per group and 7.2% in average over all three groups in the trial round only due to the display. Having a closer look on the first round the savings related to the visualization of the energy consumption are between 6.6% and 9.7% per group and on average 7.6% over the three groups with a display compared to the control group.

Round	Group	N	Mean (l/bolt)	SD (l/bolt)
T	C	40	10.76	0.85
	T1	40	10.18	1.15
	T2	40	9.87	1.04
	T3	40	9.90	0.92
1	C	40	10.68	0.67
	T1	40	9.98	1.19
	T2	40	9.64	1.25
	T3	40	9.98	1.09
2	C	40	10.72	0.72
	T1	40	10.08	1.39
	T2	40	9.60	1.38
	T3	40	7.54	1.41

Table 1: Energy consumption within the three rounds.

Table 2 illustrates the mean consumption of compressed air ordered by group. Interestingly no noteworthy learning effects in terms of energy efficiency can be seen when comparing the mean consumption per bolt between the periods for every single group. This is an important finding because occurring differences between the groups and periods will be based on the different treatments and not on potential learning effects regarding the usage of compressed air.

While the consumption of the groups C, T1 and T2 remains relatively constant over time the consumption of group T3 drops from round one to round two by 24.4%. This implies two major findings. First of all, the purely confrontation of the participants with a video showing nature sceneries to build environmental awareness as done with group T2 has no impact on the energy consumption behavior of people. Only staff training on how to save energy while doing a certain task, not related to any environmental issue, leads to significantly decreasing energy consumption as it can be seen in the results of group T3. As expected the movie which was unrelated to the whole experiment and presented to the control group and T1 had no influence on participants' behavior.

Group	Round	N	Mean (l/bolt)	SD (l/bolt)
C	T	40	10.76	0.85
	1	40	10.68	0.67
	2	40	10.72	0.72
T1	T	40	10.18	1.15
	1	40	9.98	1.19
	2	40	10.08	1.39
T2	T	40	9.87	1.04
	1	40	9.64	1.25
	2	40	9.60	1.38
T3	T	40	9.90	0.92
	1	40	9.98	1.09
	2	40	7.54	1.41
Total	T	160	10.18	1.05
	1	160	10.07	1.13
	2	160	9.48	1.73

Table 2: Energy consumption within the four groups.

To get a deeper understanding of the discussed findings the boxplot in figure 4 visualizes the results, differentiating between the three rounds of the experiment and additionally between the four groups. What becomes very obvious here is that the energy consumption of different people varies considerably. While the 25th percentile (lower quartile), the 75th percentile (upper quartile) and especially the medians are rather similar over time for groups C, T1 and T2 the consumption of group T3 in the second round is strongly affected by the additional information on energy saving and therefore drastically lower as discussed above.

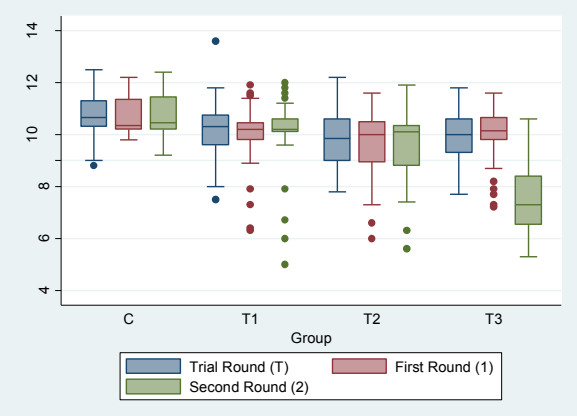

Figure 4: Boxplot of the consumption distribution.

In order to figure out if the consumption differences between the four conditions in that experiment are statistically significant the results of a Bonferroni test for each of the three rounds was executed. Based on the number of experimental groups a multiple comparison of the means

between all groups is done in table 3. In this table the means of the consumption are compared group by group and the differences are shown with a positive or negative sign in front of the mean value difference. In the trial round group T1 which had the visualization on the consumption uses on average -0.575 l/bolt less than group C who had no feedback on the energy usage. Additionally to the mean savings per round measured in l/bolt the related significance levels are shown in the table always below the number of the mean savings. In this example p=0.065 and with p>0.05 not significant on the 5% level. Therefore, the difference in this comparison is not statistically significant.

Trial Round

Row Mean – Column Mean	C	T1	T2
T1			
deviation	-0.575		
p-value	0.065		
T2			
deviation	-0.8875	-0.3125	
p-value	0.001	0.978	
T3			
deviation	-0.8525	-0.2775	0.035
p-value	0.001	1.000	1.000

First Round

Row Mean – Column Mean	C	T1	T2
T1			
deviation	-0.695		
p-value	0.026		
T2			
deviation	-1.04	-0.345	
p-value	0.000	0.917	
T3			
deviation	-0.6975	-0.0025	0.3425
p-value	0.025	1.000	0.935

Second Round

Row Mean – Column Mean	C	T1	T2
T1			
deviation	-0.635		
p-value	0.155		
T2			
deviation	-1.1175	-0.4825	
p-value	0.001	0.536	
T3			
deviation	-3.18	-2.545	-2.0625
p-value	0.000	0.000	0.000

Table 3: Comparison of the mean consumption (in [l/bolt]).

By taking a closer look on the results of the second round it can be seen that the mean consumption of group T3 is 3.18 l/bolt lower compared to the control group. Below that value the p-value is given. The related p-value to the value 3.18 l/bolt is 0.000, and with $p < 0.001$ highly significant. For the second round of the experiment all p-values of T3 compared to the other groups are 0.000 and therefore highly significant on the 1% level. This supports the findings of the descriptive comparison of the means for the second round in table 1 and 2 as seen above.

4.2 Gender differences

Because of the fact that the number of female participants in the experiment is equally distributed over the four groups the consumption between male and female students can easily be compared. The results in figure 5 show that the consumption levels of both genders are nearly at the same level comparing every single round and every single condition separately. Female participants on average over all groups consumed 9.43 l/bolt and therefore a little less than their male counterparts who consumed on average over all groups 9.51 l/bolt.

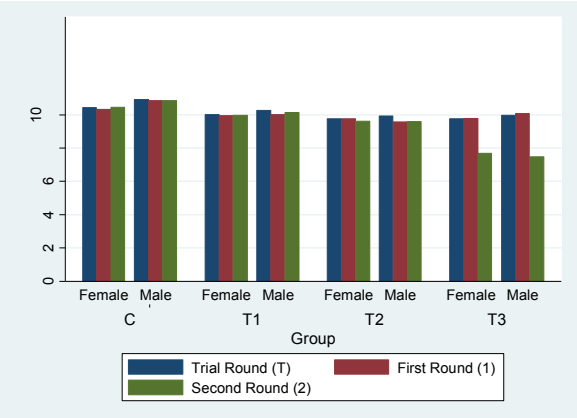

Figure 5: Consumption comparison by gender.

4.3 Goal changing behavior

In the questionnaire after the experiment students were asked to name their major goal for each of the two rounds. They had to choose between either a) produce high quantities (Quan), b) avoid mistakes (Qual) or c) save energy (Energy). Table 4 shows separately for round one and round two the answers of the participants, differentiating between the four experimental groups. The numbers in brackets show the percentages of students per group which chose a particular goal.

For groups C, T1 and T2 it can be seen that the number of students who named as their major goal to produce high quantities rose from round one to round two tremendously. Over the three groups the percentage increased from 33.9% to 73.5%. In comparison the number of students who were trying to avoid mistakes or save energy decreased strongly in these groups between the rounds.

Round	Group	N	Quan	Qual	Energy
1	C	40	16 40%	24 60%	0 0%
	T1	40	13 33%	17 42%	10 25%
	T2	38	11 29%	20 53%	7 18%
	T3	39	23 59%	16 41%	0 0%
	Total	157	63 40%	77 49%	17 11%
2	C	40	34 85%	6 15%	0 0%
	T1	40	27 68%	8 20%	5 12%
	T2	37	25 68%	6 16%	6 16%
	T3	39	15 38%	3 8%	21 54%
	Total	156	101 65%	23 15%	32 20%

Table 4: Change of participants' main goal between rounds.

In contrast, participants of group T3 changed their behavior in a different direction. More than 50% of them were looking mainly on reducing energy consumption in round two, while none of them called energy savings the main goal in the first round.

Based on these results it becomes obvious that in case people get more confident and familiar with a certain task they tend to focus more on producing high numbers while taking less the quality and the energy consumption into account. In contrast to that people who get a certain external impulse on how to change behavior related to energy efficiency, these people do focus more on that goal dimension. These findings are supported by the comparison of the increase of inserted bolts. While all groups completed on average 72 – 74 bolts in the first round the groups C, T1 and T2 realized 79 – 82 bolts in the second round while T3 grew only slightly from 74 to 75 bolts in the second round.

4.4 Results summary

To sum up the most important findings of the study are:

- Energy can be saved only by visualizing the consumption.
- General sensitization regarding environmental awareness has no effect on behavior.
- Workers have to be sensitized and trained on the specific topic to behave in a more energy efficient way.
- Between females and males no significant behavior differences related to energy saving behavior exist.
- Even without financial incentives people do change behavior based on additional information.

5 CONCLUSION AND OUTLOOK

This paper presented a study to analyze the influence of energy consumption visualization and task-related information on workers' behavior. To conduct this experiment a work station to assemble gear boxes with a pneumatic screw driver was chosen and the behavior of 160 participants analyzed. Four different groups consisting of 40 participants each were defined and separated in different treatments. Generally, the strength of the influence of workers' behavior on the energy usage in a certain production step became obvious. The most important findings are that simply showing the consumption of compressed air during the production process to the worker reduces the consumption by around 7%. By giving additional task-related training with a focus on saving energy participants reduced the compressed air consumption by additional 24%. There haven't been found any significant differences between the results of female and male participants.

Future research should first replicate the scenario in a completely real production setting in industry to validate the results of that experiment. Furthermore, other related topics should be tested in the LEP-setting to gain further insights on human behavior and the reaction on consumption visualization, additional task-related information or other related topics to enable and foster energy efficient behavior.

To ensure that the experimental setting is as close as possible to a real production environment the three main goal dimensions in production settings namely energy efficiency (in broader terms material efficiency), product quality, and produced quantity have to be taken into account jointly.

6 ACKNOWLEDGMENTS

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