Indicators for Self-assessment of Human Practices in Homes

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Abstract: Usage indicators are proposed in smart buildings in order to analyze occupant behavior towards energy usage. Indicators are a means of communication to interact with occupants of a living area so they can make informed decisions regarding their everyday customs and uses. Through them, occupants will be able to compare and challenge themselves with others or with their past results. Moreover, occupants will be able to understand the consequences and effects of their energy behavior and learn how to improve it without degrading their comfort. Heat flow through door/window indicators (heat losses), and dishwasher indicator have been calculated and discussed in an apartment context. There were 70 heterogeneous sensors previously installed to gather the information needed. These indicators have been evaluated by considering three conditions: measurable/calculable, understandable and comparable/challengeable between different houses or users. Studying and measuring different indicators give a sort of energy performance of a building, which in turn helps to improve automated building management tools.

1 INTRODUCTION

The residential sector is playing an essential role in the context of overall energy consumption. Indeed, the limit is not certain but the amount of energy usage can be minimized up to a certain extent so as to balance the energy flow. Hence, it can be said that the energy efficiency is an important challenge in today's area of building and automation system, but how one can minimize the energy consumption and how human behavior plays a vital role in regards to the energy consumption of the living area?

Today, there are numerous services and tools available which provide the exact information about the amount of energy being used by any particular appliance or service in a living area. However, the biggest questions coming out of those statistics is that: whether one can improve energy efficiency using less energy for the same service or not. How human behavior is playing a vital role considering the main focus is to reduce the overall energy consumption while keeping the comfort level.

Energy savings depend on the conscious action of the inhabitants, which is not likely to be constant over time. Thus, lots of work have been focused on developing energy intelligent buildings by integrating occupant activity and behavior as a key element for building management systems with which the buildings can automatically save energy. For this purpose, indicators are an important part to help to build better automation building management tools but also to show a visual use of energy performance to the inhabitants coming from their own daily behavior on the building. In order to understand the energy Usage and act in accordance with that, some indicators are required, which can estimate the cause and effect of the particular action in regards to the overall energy consumption.They aimed at synthesizing several data, which occupants would not be able to understand separately and make it intelligible. Indicators are divided or categorize depending on what they measure, there are: (1) technical indicator: showing the performance of the building, (2) usage indicators: showing the amount of energy used or wasted, which is directly or indirectly related to occupant's actions on a daily basis (cost is also included here). Another type of indicator is (3) comfort indicators: like thermal or air quality comfort. They show how the actions of the occupants affect the comfort levels inside the house or building.

This paper tackles this issue by proposing and analyzing some usage and comfort indicators. Section 2 presents a state of the art about indicators and building performance. Section 3 deals with energy consumption practices factors. Section 4 proposed different indicators. Section 5 focuses on data collection and

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apartment case study. Section 6 results of heat flow and dishwasher indicators.

2 STATE OF THE ART

Following the electricity trends and the design of the new smart buildings, several solutions were developed in regards to saving the energy consumption inside a building. (Nguyen, 2013a) concluded that there is a possibility of 58% saving on energy for lighting and 10-40% for HVAC system. Some other studies like (Georgievski and Degeler, 2012) which were conducted in the commercial sector showed an average economic saving of about 35% by presenting an approach based on measuring energy consumption on individual user activity and service.

Some appliances and services are very dynamic and uncontrollable, (Nguyen, 2013b) illustrates the different application of information feedback method in order to save energy consumption in a living area. He presented the findings of a UK based field study involving 44 households considering domestic cooking: he compares the effectiveness of providing paper-based energy-use/saving information with electronic feedback of energy-consumption via ECIs (Energy Consumption Indicators) designed specifically for this investigation. Twelve Control Group households were monitored for a period of at least 12 months and it revealed an average daily consumption for electric cooking of 1.30 kWh. Subsequently across a minimum monitoring period of 2 months, 14 out of 44 households achieved energy savings greater than 10% and six of these achieved savings of greater than 20%. The average reduction for households employing an ECI was 15%, whereas that given antecedent information alone reduced their electricity consumption, on average, by only 3%. The associated behavioral changes and the importance of providing regular feedback during use were identified by them. The study (ref, 2017) illustrates that building energy use is mainly influenced by different factors: climate, building structure, building services and energy systems, building operation and maintenance, occupants' activities and behavior, and indoor environmental quality. Among these factors, the last three ones are human-related factors which can have an influence as significant as the first three.

In (M. G. Ellis and Gigawatts, 2009) represent that now most new appliances have designed to utilize up to 40% less electricity which is not quite enough to insert them into the class of smart appliances. One feature of smart appliances is that they are designed to be able to measure their own power consumptions and it uses this data to conserve electricity and money, in addition being programmable. However, there are some home automation solutions available to use wireless technology, as well as existing wiring's home to be connected and automated appliances.

The road toward energy efficiency is reached, in part, with the implementation of the smart appliances and smart meters, and the need of indicators become somewhat very important to collect and give form to all human behaviors which directly or indirectly affect the usage of the energy. Indicators play a big role to reach the European Union target of 2020 (ref, 2018a). Knowing all the details about the energy consumption is not always enough, to make sure that the occupant is going to reduce energy consumption. Therefore, it is also required to make a link between all the waste towards the occupant behavior and represent it in such a way that an occupant can understand it and act in accordance with. The study of this paperwork to involve the idea of such an indicator and a way how can a better indicator be designed keeping more pragmatic towards the occupant approach as a sustainable solution.

3 ENERGY CONSUMPTION PRACTICES FACTORS

Human behaviors regarding energy consumption are complex but it is possible to grasp some factors about energy consumption behaviors and how to change behaviors on a long-term basis. First, people often act differently as they say they will, but they feel some discomfort from this situation. It is called "cognitive dissonance" (L, 1957). People also tend to sustain their behavioral changes when they get committed in public. The induced hypocrisy paradigm (Isabella Gaetani, 2010) is based on these observations: the mechanism aims to artificially recreate a cognitive dissonance situation. Once a person gets committed, it is important to recall his commitment every time it is transgressed. The work in (Isabella Gaetani, 2010) also underlines the importance of belonging to a group, i.e. a community. Besides, people are reluctant to change. Imposing a change to people is badly abided. To get a change in a behavior, you have to obtain the will of people and make them feel like nothing is demanded (Isabella Gaetani, 2010). In other words, you have to find a way to involve them in decision making. Moreover, understanding the nature of practices is a way to make sure that the changes will be sustainable. Practices are at the junctions of three elements: a meaning, a material dimension and some competences (Shove E., 2012). Changing a practice should take simultaneously into account these three elements. Therefore, the creation of indicators must rely on a meaning shared with the users, being supported by a device or an application easily understandable and useable, and they must not require expertise on energy efficiency because it can't be assumed that targeted users of indicators know a lot about energy. In addition, energy consumption practices respond to "logic of action", i.e. all the actions carried out to achieve an ideal. This ideal is based on some sociological norms and values. Several logic actions have been identified to highlight the interactions between a device (which goal is energy efficiency) and an user (S, 2015). They can be easily transposed to the creation of an indicator:

- comfort at home
- seek for fun in the use of technologies
- desire to control the housing and life
- interest for every element related to energy
- economical behavior
- ecological behavior

But energy efficiency is not a goal that only concerns inhabitants. In fact, this problem affects different publics: consumers of course, but also citizens, energy operators, local authorities. These different publics do not meet the same goals. Indicators must embrace this complexity to be more accurate. Feedback must be taken into account as another dimension related indicators requirement. Delivering information about energy consumption is not enough to lead to behavior changes. Consumers need accurate information to understand how they consume. Two questions arise from this assessment:

- what should be the temporality covered by feedbacks?
- what should be the spatiality covered by feedbacks?

These questions are dealing with the rapidity and precision for information delivery about energy consumption to obtain commitment and long-term changes.

Firstly, indicators should provoke desire to act, by mobilizing social norms and values that guide the energy behaviors of users. Secondly, users must have the capacity to react to the messages delivered by the indicators. As a consequence, energy efficient appliances linked to sensors and indicators have to be easy to use. Thirdly, delivered messages by the indicators have to be understandable by non-expert users.

Regarding the temporality, it depends on the nature of the indicator itself and the glimpse the user would like to get. It can go from one second to one year. Regarding the spatiality, it has been underlined earlier the importance of being part of a group to achieve a sustainable change. That's why it is also recommended to develop meaningful and shareable indicators. Using comparison can help people to position themselves and strengthen their commitment. From the energy point of view, the evolution of smart grid to the smart meter and smart appliances there are many ways to measure the consumption of electricity, with the help of these measurements, more new challenges come into consideration.

4 PROPOSED USAGE INDICATORS

Improvements in the energy performance of a building cannot be achieved at the expense of the comfort of building occupants. Consequently, it is necessary to measure the comfort levels within the building in order to ensure that primarily the occupants of a building are comfortable and also to ensure that all legal requirements related to comfort are satisfied. Thus, these indicators are designed to inform both building managers and building users on the impact of their behavior on the performance of the building. Below are the proposed indicators related to usage.

4.1 Heat-flow Indicator

This indicator is a usage indicator for the energy loss (turn on the heater/air conditioner, open/close a door/window). The first step is to link this indicator with the occupant's actions in the house. What are the actions responsible for the loss of heat produced in the house, and what actions must be taken in order to avoid it and have a good indicator of reading?

4.1.1 Heat-flow Indicator through the Window

In a room, there are 2 main ways for the heat to be wasted, through the window or through the door. Before calculating heat flow indicator through these 2 factors, there are 3 conditions that must be met to be a waste:

1. heater or air conditioning systems must be on.
2. window must be opened during the calculation time.
3. CO2 concentration should be below 1000 ppm, as stated in (ref, 1969) (if the CO2 levels are higher

than the calculation of heat loss is not done that because opening the window was necessary to freshen the air quality)

Finally, the indicator is calculated as a difference in temperature between outdoor and indoor temperature. (i.e. number of waste degrees) The proposal formula of the algorithm is presented as such equation 1:

$$\int pos(T_{in} - T_{out}) window_{position} threshold (co_2) dt heater_{status} \tag{1}$$

This formula is for calculation of heat flow during winter, when there is positive heat flow through the window to outdoor when it is too cold outdoors. Vice versa during summer the calculation is done when there is positive heat flow through the window from outdoor when it is too hot outdoor, equation 2.

$$\int pos(T_{in} - T_{out}) window_{position} threshold(co_2) dt conditioner_{status} \tag{2}$$

4.1.2 Heat-flow Indicator through the Door

Heat-flow though the door is the same as the one for the window with the only exceptions being the position of the door opening and the heat flows not outside but on the corridor, equation 3 and equation 4.

$$\int pos(T_{in} - T_{corridor}) door position threshold(co_2) dt heater_{status} \tag{3}$$

$$\int pos(T_{in} - T_{corridor}) door position threshold(co_2) d conditioner_{status} \tag{4}$$

Thus, this indicator provides data on the difference in interior and corridor temperatures for time periods, where the door should be opened.

1. heater must be ON, otherwise, there is no energy lost from heating.
2. window must be opened during the calculation time.

4.2 Dishwasher Machine Indicators

Since appliances are responsible for around 20% of the total energy consumption (ref, 2018b), it makes sense that the usage of these appliances should be focused. The first step is to link their consumption with the occupant's interaction with these appliances. Dishwasher machine data has been investigated, where two indicators have been extracted from their recorded power consumption:

1. dishwasher machine average consumption during each cycle.
2. number of cycles (daily, weekly,....).

5 RESULTS

5.1 Apartment Case Study

A residential apartment in Grenoble, France has been investigated, which is considered as a multi-zone application with lots of sensors and different activities. The setup for the sensor network includes 70 sensors:

- temperature sensor in each room.
- motion sensor in each room.
- windows contact sensor in each room.
- doors contact sensor in each room.
- power consumption sensors in the kitchen (i.e, dishwasher, clothwasher, ...).
- appliances power consumption sensors in each room.
- humidity sensor in each room.
- uminosity sensor in each room.

It consists of two bedrooms, a common room, a kitchen, an office, a separate bathroom, and toilets. The doors and windows are equipped with contact sensors providing binary numbers related to the state of the doors or windows i.e. 1 for open and 0 for closed. Only the contact sensors give values as binary state whereas the rest of the sensors measure their respective variables to the extent of the intensity i.e. the luminosity in the kitchen.

- washing machine average consumption for each machine cycle (for all users or per user) indicator.
- dishwasher machine average consumption for each machine cycle (for all users or per user) indicator, where a cycle is a one working phase of the dishwasher machine.
- a number of cycles indicator (i.e washing machine, dishwasher machine...).
- heat float(loss of heat) through a door/window indicator.
- CO2 average concentration indicator.
- comfort ICONE indicator.
- fridge usage indicator.

In this paper the discussion is focused on two types of indicators:

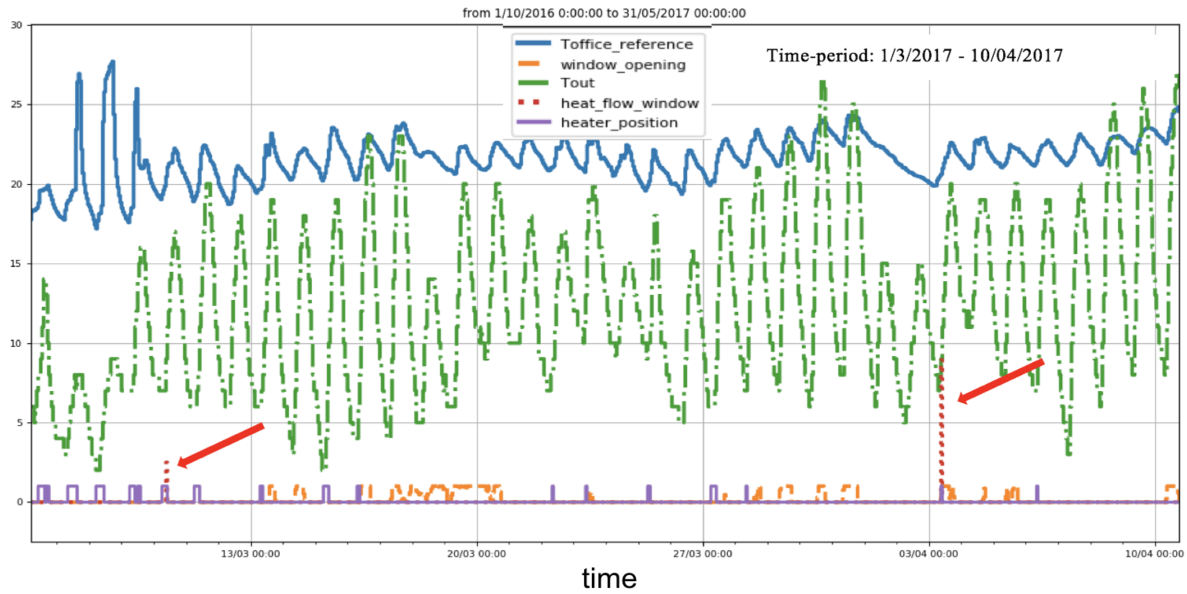

Figure 1: Heat flow through window, overview of temperature differencesy.

1. heat-flow indicator (through door/window).
2. dishwasher indicators.

The data coming from the sensors was recorded and monitored from December 2015 to August 2017 in the apartment case study, one room is chosen to do the experiment of indicator calculation (office room). Fig. 1 presents the heat flow indicator in one room through the window. The blue curve is the indoor temperature, the green is the outdoor one, and in red is the indicator. Only in 2 instances, there has been a heat loss or a flow of heat from indoor to outdoor for this case, which show a good behavior of the user. Fig. 2 presents the heat flow through the door, a different story can be seen. During the whole winter, there is a lot of heat flow from the room to the corridor (green curve), where the door openings. In this case, the difference between room and corridor temperatures are highly affected by the heat flow.

Following the objective of indicator design, for heat flow indicators they can be got 2 pluses for 2 criteria, namely understandable and comparable, but only one plus for the measurable criteria. The reason for this is because even though it is very easy to Calculate, the information needed (i.e. reading window and door openings), it's not common to be installed in every house or building. But for the other 2 criteria, it is easily understandable and comparable.

- measurable/ calculable + (1 plus)
- understandable ++ (2 pluses)
- comparable/ challengeable ++ (2 pluses)

Fig. 3 shows the weekly consumption of the dishwasher machine for 3 different houses, this value will be more interesting for the end user if it is presented as average consumption each cycle (see Fig. 4(b)).

In order to compare the usage from different dishwasher machines, we must link their usage with a user's activity, in this case, the number of cycles used during the week on average. (see Fig. 4(a)) shows the number of cycles each week for three different houses A similar conclusion can be done for this indicator, they are easily measurable and calculable, as well as comparable with different houses. The consumption of the appliances is directly linked with the number of cycles, which can give the user a simple and motivated way to be in challenged and to compare with other users. For example, some challenges can appear between the greenhouse and the orange one. Both houses have almost the same number of cycles (Fig. 4(a)), but the greenhouse has less consumption compared with the orange one (Fig. 4(a)).

- measurable/ Calculable + (1 plus)
- understandable + + (2 pluses)
- comparable/ Challengeable ++ (2 pluses)

6 CONCLUSION AND FUTURE WORK

Usage indicators have been discussed in this paper. Indicators are variables characterized by their values with a significant representation. Indeed, they aimed

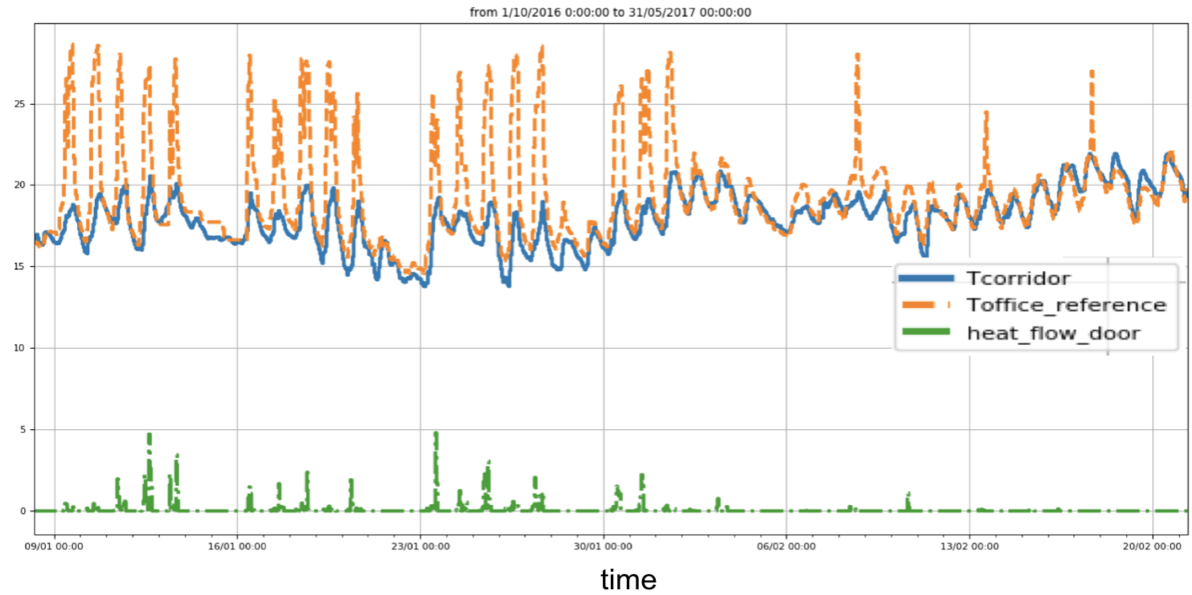

Figure 2: Heat flow through door, an overview of temperature differences.

to synthesize different information which occupants would not be able to understand separately and make it intelligible.

Among different proposed usage indicators, two have been discussed in this paper, heat flow through door/window, and dishwasher indicator, all showed a quite good presentation to the end user according to 3 criteria: measurable, understandable and comparable between different houses or users.

Depending on the responsibility of the occupants in a house, and regarding the openings and closings of the window or door, it was easy to measure and link behavior with the loss of heating as a result. This usage indicator (called Heat-flow indicator) shows good results, it is very understandable and comparable and can be applied with ease to different house settings.

Continuous work can also be done in identifying and designing new indicators as well. Probably, identifying new user's activities or even linking different indicators with each other. More indicators are however required especially indicators related to the use of high energy consuming appliances and comfort levels within a building. These are especially necessary in order to avoid achieving high energy performance at the expense of the comfort of building occupants.

In terms of the future scope of this research, it would be very interesting to make a small-scale experiment with some experimental reference values, just to know if it can work for the occupants keeping the level of comfort constant. A survey could also be very interesting to investigate or judge the user on the basis of reference values. Further, in order to know the efficiency and feasibility of the proposed indicator a large scale experimentation could also be done referring to it as magic to save the energy.

Develop a graphical user interface solution for better presenting the indicators to the end user. Finally, an important point should be investigated and develop the experimental evaluation. There is a lack of methodological guidance in the information visualization literature on how to do so. The problem is two-fold: (1) objective measures are not enough to capture the quality of a decision, given that "finding a good compromise" is by essence, subjective. Subjective measures such as self- reported satisfaction are useful but may be unreliable. (2) there is a lack of clear references for identifying an appropriate baseline for comparative assessment.

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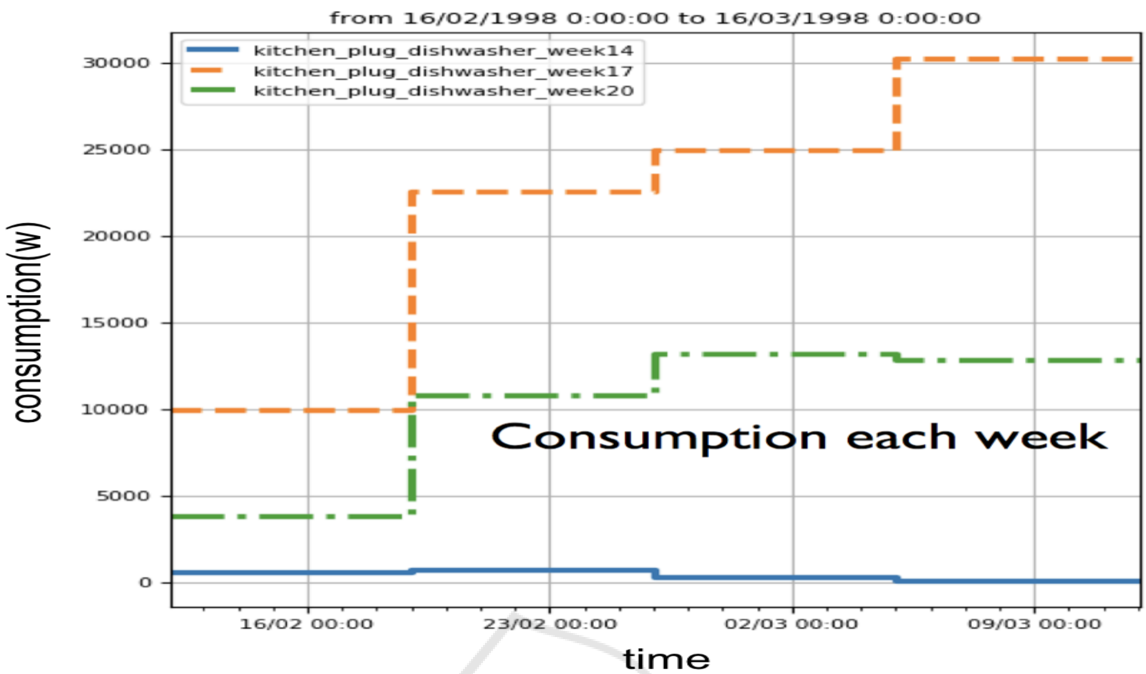

Figure 3: Different dishwasher machine's consumption.

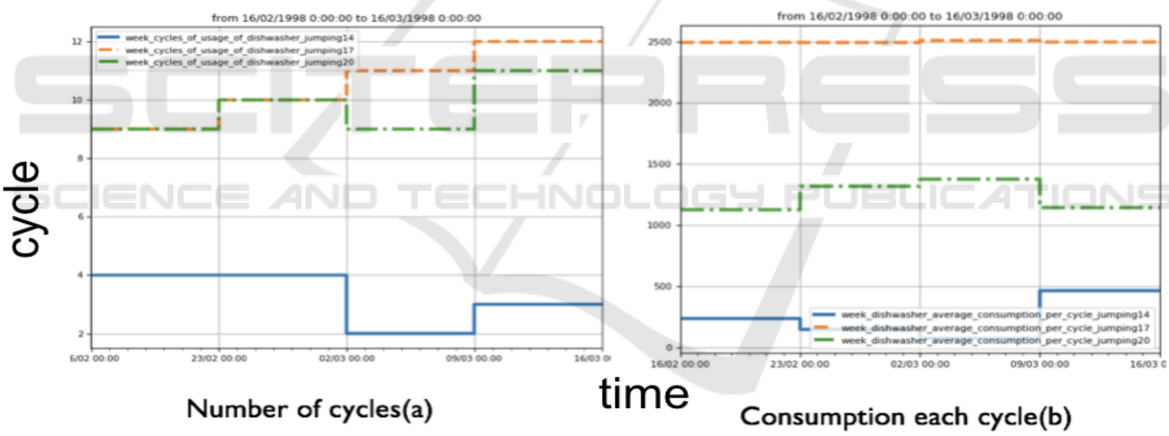

Figure 4: Number of cycles (a) and Consumption each cycle (b).

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