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Article

Using virtual choreographies to identify office users' behaviour-change priorities with greater impact potential on energy consumption

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Abstract: Reducing office buildings' energy consumption can contribute significantly towards carbon reduction commitments since it represents 10% of total energy consumption. Major components are lighting (40% of consumption), electrical equipment (35%), and heating and central cooling systems (25%). Occupants' behaviours impact these energy consumption components, with solid evidence on the role of individual behaviours. In this work, we propose the methodology of using virtual choreographies to identify and prioritize behaviour-change interventions towards office users based on the potential impact on energy consumption. It was study the energy-related office users behaviours by combining three sources of data: direct observations, electricity meters, and computer logs. Data shows that there are behaviours with significant consumption but have little potential for behavioural change impact, while other behaviours hold substantial potential for lowering energy consumption via behavioural change.

Keywords: Virtual Choreograhies; Behaviour-change; Energy consumption; Human-behaviour representation

1. Introduction

Decreasing carbon emissions has been one of the most recent global struggles, and reducing energy consumption in buildings has been widely researched and worked on [1] because it represents approximately 40% of the energy consumption. As a way to guarantee the planet's sustainability, a case study conducted in UK [2] indicates that the way forward is to implement automation systems but, where this is not possible, improve users individual behaviour will remain the best approach.

The individual user behaviours and their choices may influence the consumption patterns. For instance, in the United States alone, those behaviours are responsible for 30 to 40% of the total annual CO2 emissions [3]. The occupants' behaviours are a significant factor influencing the relevant discrepancies between buildings with the same climate location and functionalities [4]. In a typical office building, lights consume 40% of total energy, heating and central cooling systems around 25%, and the rest is from computers, printers and other electrical equipment plugs (35%) [5].

Several authors [6–8] state that the office buildings users' behaviours are the most relevant aspect that influences energy consumption. Sometimes office users leave their computers turned on (ex. lunch breaks, weekends, and night periods). These behaviours increase electricity bills and are difficult to change with automation systems, demonstrating their energy inefficiency [9].

Sets of behaviours, interactions, and associated events that occur in a given time and space, with well-defined objectives and rules can be defined as virtual choreographies [10]. The concept of such virtual representations being independent from the platform on which they are recorded and analysed or replayed emerged from efforts on analysis of multi-user behaviours in virtual training scenarios where users interact with the environment collaboratively. Also in particular scientific and research areas virtual choreographies are used [11].

Therefore, considering the role of individual behaviours in energy consumption, this work proposes the methodology of employing virtual choreographies to identify and prioritise behaviour-change interventions towards office users. The prioritisation is based on two factors: the impact of each choreography on energy consumption, and its potential for behavioural change.

Identifying behaviours is a challenge because, for example, the same action in different contexts actually represents different behaviours. Moreover, an act depends not only on its context but on sequences. On the other hand, even if all the behaviours are known, it is likely that not all of them can be modified, because that would imply generating multiple and even potentially contradictory incentives.

For instance, if, with the aim of saving energy, it is encouraged to turn off the computer when going to the bathroom is contradictory to maintaining productivity at work, because when returning from the bathroom it is necessary to wait for the computer to turn on again, which may be considered unfeasible for such a short absence and which brings little energy saving. In other words, it is indeed relevant to consider the relationship between efficiency and context.

We demonstrate how we identified relevant virtual choreographies for office building energy consumption, and how we analysed according to these two factors: energy consumption impact and potential for behavioural change. The results revealed which choreographies should be prioritised as targets for behavior change. This demonstrates the method's relevance for application in wider contexts.

This paper is structured as follows: we present the literature on the role of individual behaviour on energy consumption on office buildings, and on the representation of virtual choreographies. We then describe how behaviours were identified as choreographies and how each was assessed regarding energy consumption and behaviour change potential. Then we discuss these results and conclusions, alongside present limitations and future work suggestions.

2. Background

According to the objectives presented in the introduction, we will now look at the state of the art regarding the role that individual behaviours play in energy consumption and then how human behaviours can be represented, concluding with the theoretical approach regarding virtual choreographies.

2.1. Role of individual behaviours in energy consumption

Reducing the energy consumption in buildings is a critical component towards the carbon reduction commitments and has become a growth relevant area of work and research [1], they represent approximately 40% of the energy consumption [12]. According to the Buildings Performance Institute Europe report of 2011 [13], office buildings account for 26% of the total energy consumption within the building sector.

Regarding the low carb emissions studies [2], they recommend that the future should use the greening business and improve the automation systems, not forgetting the individual behaviours. The individual user behaviours and their choices may influence the consumption patterns also, those

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individual behaviours are responsible for 30 to 40% of the total annual CO2 emissions in the United States [3]. However, few studies address the issue of individual behaviour in organisations/companies, as discussed below: the research has mostly looked into the actions of users more in the context of households.

We can split the energy consumption in buildings into two types: regulated and unregulated components [14]. The total operational energy consumption of regulated components, such as heating, cooling, hot water, fans, and pumps, is generally well optimised. However, the consumption patterns associated with unregulated elements in office buildings like IT equipment (office printers, desktop and laptop computers), lab equipment, catering facilities, localised heating or cooling and lighting, etc. cannot be easily controlled by automation systems, because they depend mainly on human behaviours [15].

Occupants' behaviours significantly influence the relevant discrepancies between buildings with the same climate location and functionalities [4]. The way that the building occupants set their comfort levels and related criteria, for instance, thermal and visual, influences the building energy systems. In addition, the response to those environmental changes, in order to place the right comfort levels, directly affect the energy use and the overall operation of the buildings [4].

In a typical office building, lights consume 40% of total energy, heating and central cooling systems around 25%, and the rest is from electrical equipment plugs (35%) [5]. Even more relevant, if analyzing the electricity use in buildings with high-efficiency systems, the plugs load can represent 50% of total consumption [16]. We can divide the energy consumption of these types of buildings into lighting, computers and air conditioning. Several studies [16–18] indicate that it is possible to optimise the usage of these three vectors of office equipment, with considerable energy savings, by changing individual users' behaviours.

There are several factors those users behaviours depends on (economic, ethics and social related) making it difficult to change with automation systems increasing electricity consumption. For instance, sometimes users frequently leave the computers turned on for long periods (lunch, weekends, etc.) [9].

A study conducted in the US, on office buildings, by Weber [19] states that most of the electric equipment is always on, and almost 90% of desktop computers are not configured to enter low-power 50% of the computer monitors enter safe mode. Another study [20] based on the quantities of energy wasted during non-occupied hours in commercial buildings highlights opportunities for implementing individual behavioural changes on services buildings.

Many mechanisms are used in the design phase of buildings that can predict, using simulations, the total energy consumption. However, there is a considerable difference between the expected consumption and the effective one. Individual behaviours and the occupants' preferences are some of the most relevant factors that influence that identified difference [21]. So it must exist effective strategies aiming to understand the user awareness, expectations and concerns deeply. Therefore, many research surveys [22–24] were conducted to exactly pursue this deeply understand the consumer preferences about energy consumption and their perceptions related to demand response and energy efficiency behaviours. Several authors [6–8] state that the individual behaviours of the office buildings users are the most relevant aspect that influences energy consumption.

There are several researchers dedicated to studying the influence of occupant behaviours. Hoes et al. [25] propose simulation tools, however, this kind of approach does not deal with the diversity and complexity of users behaviours. Also, the use of power meters to provide the basic information on appliance consumption are used, but, these kinds of tools are not able to define usage patterns, because they were not made to disaggregate energy consumption by end-user [26].

Although some approaches [27,28] explore non-intrusive load monitoring in order to obtain data on the energy consumption of buildings at the equipment level, they still fail to correlate these consumptions with the occupants' activities. But, even if it were possible to disaggregate this information in some way, as Berges et al [29] point out, care should always be taken to correlate consumption with behaviour so as not to generate decontextualised results.

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Concluding, after demonstrating that there is strong evidence that the role of individual behaviours impacts the energy consumption of buildings, the reflection now goes on can those behaviours be represented and also how can they be analysed.

2.2. Virtual Choreographies concept and representation

Understanding human behaviour is fundamental in society, and Psychology is a scientific field that studies a broader understanding of human behaviour. However, this work object is not to study this area of knowledge, namely the theories and types of behaviour, and therefore an approach to how these behaviours can be represented in information systems now follows.

2.2.1. Human Behaviour Representation

The need to represent human behaviour from the software analysis and development point of view arose in the early 1990s when the Cold War's culmination brought new military challenges and tasks to NATO [30]. All this due to the advent of innovative technologies that were beginning to have a tremendous impact on implementing simulation systems and decision support tools. It is then that the digital representation of human behaviours becomes vital to power decision support tools and simulators [30].

Uwe Dompke is a German Air Force officer who led studies in the NATO Research and Technology Organization (RTO now STO), namely in modelling and simulation to support training, education, and decision-making, especially in the area of human behaviour representation. Regarding the term Human Behaviour, he defines it as "a purposive reaction of a human being to an idiosyncratic meaningful situation" [30]. A few years later, Elizabeth Hutchinson [31] defines Human Behavior as the interaction between a person with the environment.

In practical terms, human behaviour occurs when there is a change from one state into another (bodily and/or mentally) with a particular goal and can be externally observable. It does not have to have an associated logic nor an appropriate reaction, possessing three interconnected components (socio-affective, psycho-motor, cognitive) [30]. In order to perceive human behaviour, it also needs to take a multidimensional approach (time, person, environment) [32].

There are several references to model human behaviours. Schmidt [33] presents the PECS (Physical conditions, Emotional state, Cognitive capabilities, Social status) reference model that aims to replace the BDI (Belief, Desire, Intention) model initially developed by the philosophical expert Michael Bratman [34]. However, the US department of defence combined the PECS model and the BDI, thus presenting the Human Behavior Representation (HBR) framework to model human behaviour [30,35].

Dompke [30] states the aspects that should be considered when modelling human behaviour:

- Considering that the human behaviour has a purpose, besides modelling that behaviour, there should always be associated a SMART (Specific, Measurable, Acceptable, Realistic and Timed) objective;
- The associated goal should represent the optimal behaviour;
- In a simple way, to model a behaviour, it should be necessary to determine the initial value(s), the process that leads to the result and the change to achieve the goal;
- It should be represented those behaviours that are relevant to the analysis needs;

The main goal of the HBR approach is to create a computational model of human behaviour that can express the observed variability in behaviours according to differences in the person's characteristics, to differences in the situation or to the interplay of both [36].

2.2.2. Onthologies

Another perspective in the area of behaviour representation relates specifically to behavioural change, which is one of the pillars underpinning this research work. For behavioural change to occur, it is necessary to identify a set of activities specially designed to change specific behaviour patterns.

These patterns are measured by the number of times they occur in a given population group under study [37].

There are methods and ways to report, evaluate and understand behavioural change interventions through specific rating techniques [38]. Medicine and the natural sciences are, in fact, the leading exponents of these approaches [39] with the use of taxonomies [40,41]. However, ontologies, as described in a scoping review led by Norris et al. [38], "extend the hierarchical nature of taxonomies" by presenting the following advantages:

1. They allow unique identification of entity types (objects, attributes, processes), thus eliminating ambiguity;
2. They enable the precise definition and classification of these identifiers;
3. And also help organise the relationships between these identifiers;

Therefore, in comparison with taxonomies, ontologies allow a greater and more detailed knowledge at the level of the representation of behaviours [38]. They also allow different theoretical perspectives with the help of conceptual frameworks and make it possible to compare multiple fields of study with large datasets [42,43]. It is also a relevant fact that ontologies allow manual updates according to the evolution and development of the domain itself, enabling a permanent update [44].

The use of ontologies has indeed been revolutionary in several domains (computational modelling of biological systems [45], creation of repositories accessible to the scientific community [46]. Given the significant impact of ontologies in other areas of knowledge, the scope of behavioural change is also included, namely with the Human Behaviour-Change project[1] [47]. This results in a collaboration between several areas of science (behavioural scientists, computer scientists and systems architects), proposing tools and guidelines that help researchers and others interested in behavioural change thematic [38].

But how are ontologies used in Information science?

There is space for the use of ontologies whenever semantic contexts are used or needed, i.e., giving meaning to information [44]. In this sense, the consortium responsible for standardising the technologies associated with the World Wide Web[2] has defined an OWL (Web Ontology Language) [48] as being responsible for representing ontologies in information systems. In computer science, an ontology is defined as a formal definition (through a well-defined syntax and semantics language) of concepts and their relationships for a given domain [44].

In practice, two fundamental components allow designing the semantic application (knowledge base and inference engine). The knowledge base is entirely linked to the ontology schema (what kinds of statements are possible) and to the facts, represented through a formal language [44].

2.2.3. Understanding a choreography

Despite the approaches previously listed (HBR and the pure use of ontologies) for representing human behaviour in the context of behavioural change, it is considered that given the need for a more simplified approach and the different characteristics present in the context of this thesis (behaviours related to energy consumption in office buildings), the use of virtual choreographies will be the approach to take into consideration.

We usually use the term choreography when referring to “the skill of combining movements into dances to be performed” or “the movements used by dancers especially in performing ballet, or the art of planning such movements” [49].

From a computer science point of view, the term is also used as a new view on interacting services associated with the “Web Services” technology [50]. Even exists a Web Service Choreography

[1] https://www.humanbehaviourchange.org/, last accessed in 2020-12-02
[2] https://www.w3.org/OWL/ last accessed in 2020-12-02

Description Language (WS-CDL[3] that supports a top-down approach in the design and implementation of those services.

However, the approach to the term that will be considered in this work corresponds to the following definition: Choreographies are sets of behaviours, interactions, and associated events that occur in a given time and space, with well-defined objectives and rules [10]. Those choreographies can be performed by human-controlled actor and/or computer-controlled actors, also known as "bots" or "non-player characters" [51]. They enable the analysis of the behaviours independently from the technological platform they occur [52], and their reproduction in different platforms to serve different needs [53].

There are several contexts that need to use collaborative virtual systems based on multi-user behaviours that include choreographed scenarios(e.g., aircraft maintenance [54], industry simulator [55], disaster simulator [56]). Furthermore, in research, virtual choreographies are also included in some scientific experiments [11].

All these contexts allow us to test and validate hypotheses that would otherwise be difficult to execute, significantly improving the predictive capacity of phenomena [57,58]. On the other hand, using virtual choreographies enables them to be designed in a platform-independent way, looking more at the context of the knowledge domain and not so much at the technological platform itself [10]. This independence of the platform allows the choreographies to be applied to different areas, such as process management [11], generating models for training and certification scenarios [59], and also transporting them to be analysed by other tools [60].

However, considering that this work aims to identify which behaviours can reduce energy consumption, it is relevant to identify how to represent these behaviours. In this sense, the direction of the present research will consider the reference previously identified in the previous section to the use of ontologies in behavioural change and the approach taken by Silva et al. [61], which presents the choreographies representation through an ontology-based model.

It is necessary to create a choreography to take into account the following elements:

- Actors: characters that perform the behaviours on a choreography. Wich includes both human-controlled and computer-controlled actors;
- Action: is a specific interaction within the environment; for instance, actors walking, gesturing, talking, manipulating, etc., as are automatic doors opening or machines running;
- Objects: elements that are not actors but can be interacted upon by actors;
- Roles: higher-order semantic context of an actor or object, providing meaning for their actions, location, and overall features;
- Scenario: the stage where a choreography takes place. It may include objects and general characteristics (such as daytime, gravity, etc.);
- Space-time: dynamic changes and evolution of the choreography, as actors and objects under specific roles and interact with each other upon the scenario over time.

3. Behaviour Identification with Virtual Choreographies

In the present research, in order to be able to identify the choreographies that contribute the most to energy consumption, two relevant steps were carried out. Firstly, the individual behaviours performed in an office that potentially consume electricity (corresponding to this section) were identified, resulting in a set of choreographies. Then, following this, a process of calculating how much each of these identified choreographies consumes in terms of electricity was carried out (next section). As the study was part of a project that produced relevant tools (hardware and software), three data sources were considered (see Fig. 1):

1. Direct observation (3.1)

[3] https://www.w3.org/TR/ws-cdl-10/ last accessed in 2021-03-05

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2. Computer software that collected when the computers were consuming energy (3.2)
3. Electricity meters that showed the exact actual consumption (3.3)

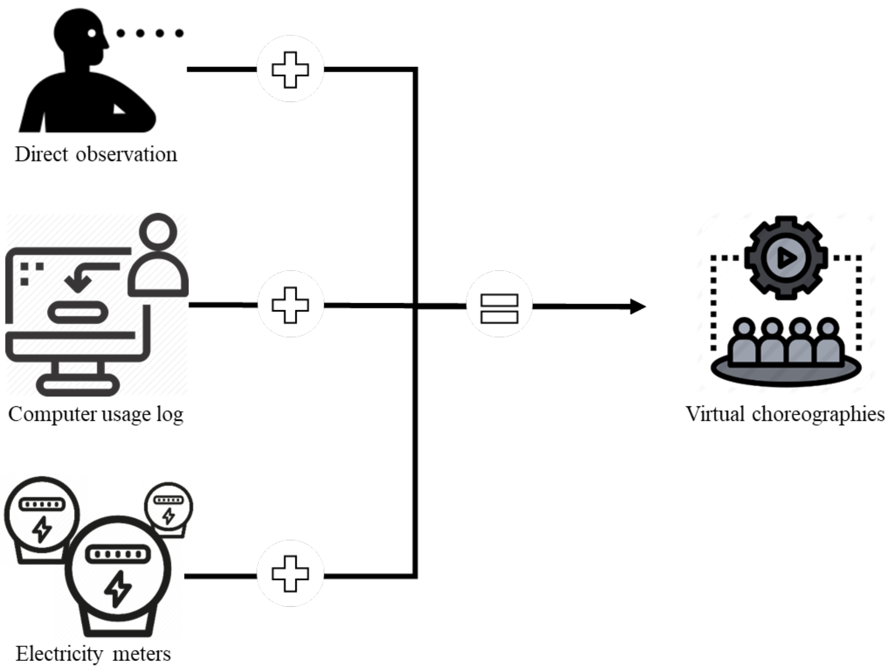

Figure 1. Sources of data that fed into the production of the choreographies

3.1. Field observation

A direct observation methodology was conducted [62] on the INESC TEC open-space office to gather the user's behaviours related to energy consumption during a specific period (one week in November 2018). Without interfering with the users and their behaviours, a researcher was present in the open space between 8:30 a.m. and 6:30 p.m. to gather observation qualitative data.

Observation procedures follow recommendations by Fox [63]: observational research can not record everything and thus responds to direct questions that are sought to be answered. For this research, the observational questions were:

- What are the usual energy-related behaviours of office users?
- How often are the energy-related behaviours occur during the day?

Regarding the first item, the observer was attentive to actions related to presence of people in the office space (which was related to lighting: no people means no need for lights) and desk work (computer usage is associated with desk work). Thus, we have recorded not only direct computer use, but also activities such as "Enter the office" and "Leave the office" due to their relationship with lighting, and activities such as "sitting at chair", since computer-based information may be relevant during that period, even if the hardware isn't actively being used.

The observational method requires a support that allows recording and subsequent evaluation of data. To minimize conditioning people's behaviour ([63]), recording was carried out by taking notes of the following observed actions among the items of Spradley [64] recommendations:

- Actor: refers to the characters interacting with the environment;
- Activity: refers to the acts that the characters carry out;
- Object: refers to the things that are present in the scenario;
- Act: refers to the individual actions of the characters;
- Time: refers to the current time which the action begins;

Actor	Activity	Object	Act	Time
a3	Work	Computer	Use keyboard & Mouse	08:31
a39	Work	Computer	Use keyboard & Mouse	08:31
a42	Work	Computer	Use keyboard & Mouse	08:31
a54	Work	Computer	Use keyboard & Mouse	08:31
a1	Enter the office	Door	Open	08:38
a1	Sitting at chair	Desk	Sit	08:38
a1	Work	Computer	Use keyboard & Mouse	08:38
a39	Leave the office	Door	Exit	08:40

Table 1. Sample observational records

Activity	Object	Act
Sitting at chair	Monitor	Turn on
Work	Computer	Use keyboard & mouse
Leave the office	Door	Open
Turn lights	Lights switch	Interact

Table 2. Distinct energy-related behaviours

This yielded the observational record, an extract of which is shown on table 1.

This observational record was analysed to identify distinct activity-object-act combinations, regardless of actors or time. These represent all the distinct behaviours related to energy consumption within the office, and are shown in Table 2, which answers the question: What are the usual energy-related behaviours of office users?

3.2. Electric power outlet meters

The existing building energy management system (BEMS) on the INESC TEC infrastructure measures the aggregated electricity consumption of the building's rooms, dis-aggregated by computer workstations and lighting using a sub-metering system [65]. As presented by Barbosa et al. [65], the main goal of the equipment is to measure the energy consumption in the most relevant circuits of the building. The sub-metering system can be divided into three parts: energy meters, gateways and a server. The energy meters are electronic devices equipped with three current transformers (one per phase) that allow obtaining energy-related information (voltage, electric-current, frequency, etc.).

At 15 min. time intervals (can be configured from seconds to minutes), these electronic devices capture measurements and then send it to the gateway. The gateway has the ability to convey the meter measurements to the server (where the data will be permanently stored) as seen in table 3.

idMeter	datetimeMeasure	valueMeasure(Wh)
PT58ABEM1253_2	01/01/2020 00:01	282679
PT58ABEM1248_1	01/01/2020 00:01	357781
PT58ABEM1249_2	01/01/2020 00:01	330716
PT58ABEM1255_2	01/01/2020 00:02	1333449
PT58ABEM1254_3	01/01/2020 00:02	30686
PT58ABEM1251_1	01/01/2020 00:02	47373
PT58ABEM1250_2	01/01/2020 00:03	616117
PT58ABEM1252_1	01/01/2020 00:03	507408
PT58ABEM1253_1	01/01/2020 00:03	269181
PT58ABEM1251_2	01/01/2020 00:04	248
PT58ABEM1250_1	01/01/2020 00:04	540724
PT58ABEM1248_2	01/01/2020 00:04	412985
PT58ABEM1249_1	01/01/2020 00:05	1098
PT58ABEM1249_3	01/01/2020 00:05	33697

Table 3. Meter table example

3.3. Computer log

Following this path to understand the office users behaviours better, after perceiving that from the measurements of the meters, there was no possibility of knowing the individual's actions because the meters are grouped by rooms, emerged the necessity of getting a mechanism that allows obtaining those individual's behaviours.

Research studies about occupants' energy-use behaviours at office buildings use, to collect energy-use data of individuals, different approaches. Some install at each workstation a plug-in meter [66–68]. Others used a wifi-based occupancy-sensing method [69] considered an easy solution in office buildings because most users have a smartphone, and there is a high wifi network coverage. Also, a computer software agent was developed and installed on each computer to evaluate usage patterns [70,71]. Even an RFID based system installed on the office users was tested [72].

Considering all the possibilities, a computer software was created that captures the state of the computer, thus allowing to obtain a reliable and individualised registration.

So, the main task of the developed software is registering, one of the following computer states: unlock, lock or shutdown. The unlock, that corresponds to the active state, it is recorded when the user starts using the device. The lock that matches with low power state is registered when the user logs out (i.e., locks the computer) and the operating system detects the low power mode. Lastly, the shutdown is recorded when the user turns off or suspends the device.

Regarding the computer status monitoring software, installed on every computer of the open space, in table 4, there is an example of a registry from a particular user.

Date time	Computer state
09:53	unlock
09:57	lock
09:58	unlock
11:35	lock
11:38	unlock
11:54	lock
12:47	unlock
12:49	lock
13:09	unlock
15:02	lock
15:06	unlock
16:01	lock
17:00	unlock
18:45	lock
18:48	unlock
20:35	lock

Table 4. Computer log registry from a user example

3.4. Choreographies identification

In Table 2, we have identified distinct behaviours. However, each of those single behaviours occurs within a wider context. For instance, leaving the office at lunchtime and returning afterwards indicates a longer period without computer use, for which users may be more willing to turn their machines off, whereas leaving the office midday might indicate a shorter absence. Choreography identification consists in considering this wider context to identify sequences of behaviours with such broader meanings. This contextual meaning was sought by triangulation of the three different data sources presented above: direct observation, electricity meters, and computer logs. The outcome, presented in table 5, represents the choreographies that can be targeted for behavioural change.

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CHOREOGRAPHY	**Characteristics to identify this choreograph** (extracted from the observational registry log)
01 Enter the office (morning)	1. Must be the first registry of the day; 2. Must occur in the morning (until midday); 3. Must include the activities: a. Enter the office (opening the door) b. Sitting at the chair (turn on the monitor)
02 Small break (less than 15 minutes | short meeting, coffee, toilet, snack, smoking, etc.)	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The difference (in minutes) between the activity a) and b) must be less than 15 minutes;
03 Medium break (between 15 minutes and 45 minutes | meeting, snack, etc.)	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The difference (in minutes) between the activity a) and b) must be more than 15 minutes and less than 45 minutes;
04 Long break (more than 45 minutes | meeting, etc.)	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The difference (in minutes) between the activity a) and b) must be more than 45 minutes;
05 Lunchtime break	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The activity a) must occur during the lunchtime hours (12 a.m. to 2:30 p.m.)
06 Leave the office (end of the day)	1. Must be the last registry of the day 2. Must include the activity: a. Leave the office (exit through the door)
07 Working	1. Must include the activity: a. Work (using the computers keyboard and mouse)
08 Turn on the lights	1. Must include the activity: a. Turn lights (interact with the lights switch)
09 Lunchtime break with shutdown	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The activity a) must occur during the lunchtime hours (12 a.m. to 2:30 p.m.); 3. The computer log state “shutdown” must exist for the same timestamp.

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10 Leave the office with shutdown (end of the day)	1. Must be the last registry of the day 2. Must include the activity: a. Leave the office (exit through the door) 3. The computer log state "shutdown" must exist for the same timestamp.
11 Small break with shutdown (less than 15 minutes ∣ short meeting, coffee, toilet, snack, smoking, etc.)	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The difference (in minutes) between the activity a) and b) must be less than 15 minutes; 3. The computer log state "shutdown" must exist for the same timestamp.
12 Medium break with shutdown (between 15 minutes and 45 minutes ∣ meeting, snack, etc.)	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The difference (in minutes) between the activity a) and b) must be more than 15 minutes and less than 45 minutes; 3. The computer log state "shutdown" must exist for the same timestamp.
13 Long break with shutdown (more than 45 minutes ∣ meeting, etc.)	1. Must include the activities: a. Leave the office (exit through the door) b. Enter the office (opening the door) c. Sitting at the chair (turn on the monitor) 2. The difference (in minutes) between the activity a) and b) must be more than 45 minutes; 3. The computer log state "shutdown" must exist for the same timestamp.

Table 5. Characteristics to identify this choreograph

4. Identifying energy consumption with Virtual Choreographies and Final Results

After the three different analyses, the need arises to understand how much each choreography weighs in terms of electrical consumption. A study was then carried out that encompassed data from meters with those from the computer log, which required the use of several calculations to achieve results. Let us now understand, on three steps, how this data was obtained.

First step

The first approach was to understand whether the identified behaviours through direct observation (table 1) could be associated with the recorded data by the computer log application (table 3).

Considering that the data collected by the observation were only relative to one week, the association between the two sources was made manually, that is, filtering the two datasets through the common values (user and day/time) which was translated into table 6.

Second step

Taking the scientific approach proposed by Silva et al. [73] that advocates the use of ontologies to represent virtual choreographies, in this way, taking the items that were presented in section 2.2.3, it was thus possible to aggregate the following tables. Using the joined table 6 (observation and computer

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Actor	Activity	Object	Act	Time	Computerlog Action
a8	Leave the office	Door	Exit	16:10	lock
a52	Leave the office	Door	Exit	16:24	lock
a50	Work	Computer	Use keyboard & Mouse	16:34	unlock
a8	Work	Computer	Use keyboard & Mouse	16:34	unlock
a52	Work	Computer	Use keyboard & Mouse	16:34	unlock
a32	Work	Computer	Use keyboard & Mouse	16:36	unlock
a50	Leave the office	Door	Exit	16:41	lock
a60	Leave the office	Door	Exit	16:49	lock
a50	Work	Computer	Use keyboard & Mouse	16:54	unlock
a47	Work	Computer	Use keyboard & Mouse	17:00	unlock
a52	Leave the office	Door	Exit	17:00	shutdown
a32	Leave the office	Door	Exit	17:04	shutdown
a9	Leave the office	Door	Exit	17:21	lock
a50	Leave the office	Door	Exit	17:29	lock

Table 6. Observation table with computer log action example

log) and looking for the criteria's and characteristics indicated on table 5 it was generated a new table data that contains the identified choreography for each record action (see table 7 example).

For instance, if the observation activity is "leave the office" and the computer log action registered is "lock", there are several choreographies that can be matched. However, if we analyse the duration of the exit of that user, that is, if we look for the next record of "Sitting at chair" and the computer log records "unlock", then we have the period of time of absence and we can identify the corresponding choreography.

Actor	Activity	Object	Act	Time	Computerlog Action	Chor. ID
a8	Leave the office	Door	Exit	16:10	lock	3
a52	Leave the office	Door	Exit	16:24	lock	3
a50	Work	Computer	Use keyboard & Mouse	16:34	unlock	8
a8	Work	Computer	Use keyboard & Mouse	16:34	unlock	8
a52	Work	Computer	Use keyboard & Mouse	16:34	unlock	8
a32	Work	Computer	Use keyboard & Mouse	16:36	unlock	8
a50	Leave the office	Door	Exit	16:41	lock	2
a60	Leave the office	Door	Exit	16:49	lock	7
a50	Work	Computer	Use keyboard & Mouse	16:54	unlock	8
a47	Work	Computer	Use keyboard & Mouse	17:00	unlock	8
a52	Leave the office	Door	Exit	17:00	shutdown	11
a32	Leave the office	Door	Exit	17:04	shutdown	11
a9	Leave the office	Door	Exit	17:21	lock	3
a50	Leave the office	Door	Exit	17:29	lock	2

Table 7. Choreography identification for each Observation with computer log action example

After that, it can be obtained a new table (8), which contains the number of occurrences, by choreography for each period of the day (15 minutes slot).

Third step

After obtaining the number of occurrences of each choreography per day/hour, the challenge was to convert this data into energy consumption. To do this, we took table 3, which contains the electric consumption (Watt-hour), and calculate the consumption for each 15-minute slot. After that, we distribute this consumption over the number of occurrences of each of the choreographies, thus creating the effective weight that each behaviour has in the global consumption of the space under study (table 9).

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Begin	End	1	2	3	4	5	6	7	8	9	10	11	12	13
08:00	08:15	-	-	-	-	-	-	-	-	-	-	-	-	-
08:15	08:30	-	-	-	-	-	-	-	-	-	-	-	-	-
08:30	08:45	3	1	-	-	-	-	-	7	-	-	-	-	-
08:45	09:00	1	2	-	-	-	-	-	2	-	-	-	-	-
09:00	09:15	2	1	2	-	-	-	-	2	-	-	-	-	-
09:15	09:30	1	-	-	-	-	-	-	1	-	-	-	-	-
09:30	09:45	2	-	-	-	-	-	-	2	-	-	-	-	-
09:45	10:00	3	-	-	-	-	-	-	6	-	-	-	-	-
10:00	10:15	-	3	-	-	-	-	-	1	-	-	-	-	-
10:15	10:30	1	1	1	-	-	-	-	3	-	-	-	-	-
10:30	10:45	1	-	2	-	-	-	-	3	-	-	-	-	-
10:45	11:00	2	2	-	-	-	-	-	5	-	-	-	-	-

Table 8. Number of occurrences, by choreography example

Begin	End	1	2	3	4	5	6	7	8	9	10	11	12	13
08:00	08:15	-	-	-	-	-	-	-	-	-	-	-	-	-
08:15	08:30	-	-	-	-	-	-	-	-	-	-	-	-	-
08:30	08:45	21,30	7,10	-	-	-	-	-	42,60	-	-	-	-	-
08:45	09:00	9,89	19,78	-	-	-	-	-	59,33	-	-	-	-	-
09:00	09:15	17,60	8,80	17,60	-	-	-	-	44,00	-	-	-	-	-
09:15	09:30	10,71	-	-	-	-	-	-	64,29	-	-	-	-	-
09:30	09:45	18,40	-	-	-	-	-	-	73,60	-	-	-	-	-
09:45	10:00	17,29	-	-	-	-	-	-	80,71	-	-	-	-	-
10:00	10:15	-	31,80	-	-	-	-	-	127,20	-	-	-	-	-
10:15	10:30	10,00	10,00	10,00	-	-	-	-	130,00	-	-	-	-	-
10:30	10:45	8,00	-	16,00	-	-	-	-	112,00	-	-	-	-	-
10:45	11:00	16,29	16,29	-	-	-	-	-	138,43	-	-	-	-	-

Table 9. Electricity consumption by choreography for hour (kWh) example

This work has thus made it possible to present table 10 which results in the daily consumption, for the work week under study, for each of the identified choreographies. Which is nothing more than the sum of the daily records shown in the table 9.

Choreography ID	Day 1	Day 2	Day 3	Day 4	Day 5	Total
01	22,66	18,27	16,79	20,93	14,65	93,28
02	16,05	14,99	21,70	17,81	17,86	88,41
03	15,16	25,83	23,48	24,01	20,01	108,48
04	9,50	9,59	13,44	-	8,94	41,48
05	31,56	61,07	59,67	37,24	36,63	226,17
06	44,10	44,61	49,29	45,70	27,82	211,52
07	154,99	154,56	150,99	154,44	154,53	769,52
08	8,95	-	-	-	-	8,95
09	10,41	-	-	13,80	-	24,21
10	13,93	9,25	41,86	13,03	11,16	89,23
11	-	12,47	-	9,45	-	21,93
12	-	-	-	7,52	-	7,52
13	-	-	-	-	-	-
TOTAL	327,32	350,62	377,23	343,92	291,59	1690,69

Table 10. Daily consumption by choreography (kWh) example

5. Discussion

From a global perspective, analysing the following figure 2, which corresponds exactly to the table 10 data, we can conclude that choreography seven is the one that naturally has more power

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consumption, with 46% of total consumption, followed in extremis by five and six, which correspond to 13% of consumption.

According to the information presented, there now follows a detailed analysis of each of the identified choreographies and the potential for energy consumption reduction if this behaviour is changed. In this sense, for each action are pointed out targets that can be used to carry out the behavioural change.

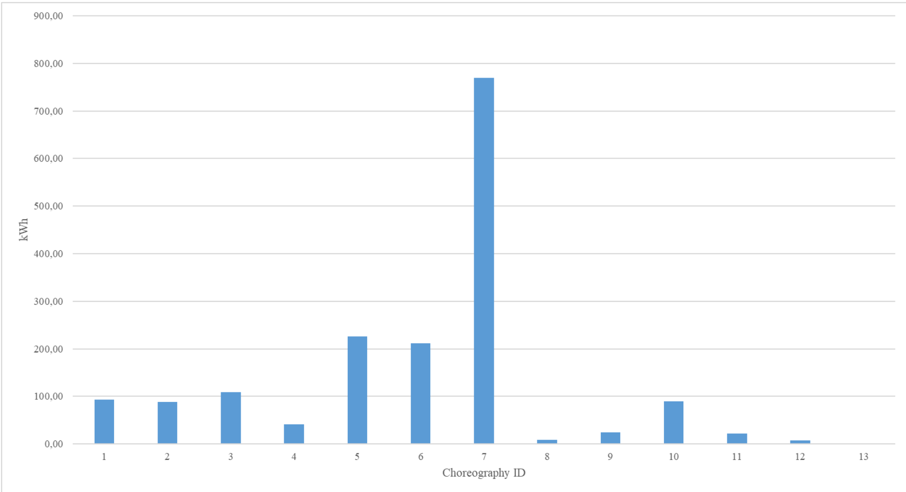

Figure 2. Overall consumption by choreography (kWh)

Choreography 1 - Enter the office (morning)
Objectively litle can be done about this type of behaviour, as it is related to the beginning of the working day.

Choreography 2 - Small break <15" (short meeting, coffee, toilet, snack, smoking, etc.)
This set of behaviours could be improved by turning off the monitor when the user gets up from his workstation. According to recent data [74], a led monitor in 15 minutes has a power consumption of about 5 Wh, which is the savings potential.

Choreography 3 - Medium break >15" and <45" (lunch, meeting, work in another place, etc.)
This set of behaviours could be improved by turning off the monitor when the user gets up from his workstation and also configure the computer to enter in power safe mode. According to recent data [74], a led monitor in 45 minutes has a power consumption of about 15 Wh and a computer in idle mode it reduces the power consumption by approximately 50%.

Choreography 4 - Long break >45" (meeting, work in other places, etc.) and **Choreography 5** - Lunchtime break
This set of behaviours could be improved by turning off the monitor when the user gets up from his workstation and also configure the computer to enter in power safe mode. According to recent data [74], a led monitor per hour has a power consumption of about 20 Wh and a computer in idle mode it reduces the power consumption by approximately 50%.

Choreography 6 - Leave the office (end of the day)
This set of behaviours could be improved by turning off the monitor and the computer when the user gets up from his workstation at the end of the journey. The potential saving could correspond to a reduction of almost 100%, however, we know that some users may need the computer turned on to access it remotely or be reluctant to deal with the long boot time at the beginning of the day.

Choreography 7 - Working
Objectively little can be done about this type of behaviour, because it corresponds to the stage when the user is working on the computer.

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Choreography 8 - Turn lights on
Using the office lights can be improved by changing user habits, namely by using natural light when available and turning them off when all the users leave the room.

Choreography 9 - Lunchtime break with shutdown
This is the desired type of behaviour for power savings.

Choreography 10 - Leave the office with shutdown (end of the day)
This is the desired type of behaviour for power savings.

Choreography 11 - Small break with shutdown (less than 15 minutes | short meeting, coffee, toilet, snack, smoking, etc.)
This is the desired type of behaviour for power savings.

Choreography 12 - Medium break with shutdown (between 15 minutes and 45 minutes | meeting, snack, etc.)
This is the desired type of behaviour for power savings.

Choreography 13 - Long break with shutdown (more than 45 minutes | meeting, etc.) This is the desired type of behaviour for power savings.

Table 11 resumes the potential savings by choreography that was previously described.

Choreography ID	Potential Savings
1	Very low
2	5 Wh per monitor
3	15 Wh per monitor
4	20 Wh per monitor and 50% consumption per computer
5	20 Wh per monitor and 50% consumption per computer
6	100% consumption per computer
7	Very low
8	Need more information
9	Very low
10	Very low
11	Very low
12	Very low
13	Very low

Table 11. Potential savings by choreography

According to the data presented, we can conclude that:

1. Choreography 7 corresponds to the use of the computer during work, which despite representing enormous consumption, in terms of behavioural change, no significant changes can be made;
2. Considering the consumption presented in choreography 5, there is space to act in terms of behavioural change during lunchtime;
3. It is also possible to address the users' behaviour at the end of the working day, since choreography 6 indicates a relevant consumption rate, besides the fact that its optimisation will certainly correspond to a considerable reduction in consumption due to what was presented before;
4. There is also a behaviour that did not translate into choreography (although it is included in choreography 6), but that was observed through the analysis of meters and computer logs, which corresponds to the fact that during the weekend many of the equipment are not turned off.

Thus, we can conclude that the behaviours that should be the targeted when designing solutions to decrease electricity consumption on the specific use case are those described in the following table.

The five targets presented in table 12, correspond precisely to the behaviours that were identified through the study carried out of the virtual choreographies. In this sense, each of the targets has the corresponding choreographies that can be used to attack each of the behaviours. The first three targets point to behaviours related with computer use. Namely to turn them off at night and on weekends,

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Target	Description	Choreography
A	Turn off the computer during the night period [8 p.m – 7 a.m.] (during weekdays)	6 / 10
B	Turn off the computer all day (during the weekend)	6 / 10
C	Stand by the computer during lunch period [12 p.m – 14 a.m.] (during weekdays)	5 / 9
D	Turn off the lights during the night period [8 p.m – 7 a.m.] (during weekdays)	8
E	Turn off the lights during the lunch period [12 p.m – 14 a.m.] (during weekdays)	8

Table 12. Identified targeted choreographies

and also to put them in stand-by mode during lunchtime. The other two are directed towards the responsible use of lights, namely to switch them off during lunchtime and at the end of the day.

6. Conclusions

Throughout this article, a method was presented which consists in identifying virtual choreographies as sets of behaviours within a broader context, by combining three sources of data: observations, meters, and computer logs. These choreographies can be assessed as targets for behavioural change, by analysing their energy consumption (computers and lights) impact and their potential for successful behaviour change. If only isolated actions were used as an analysis parameter, behaviour change success would be erratic, because there would be no distinction, for example, between leaving the computer for a short while for nature calls or leaving it for longer periods (e.g., lunchtime). This lack of contextual meaning would result in less targeted efforts. Also, the awareness of actual energy consumption impact by choreography instead of individual actions enables prioritization of behaviour-change efforts, towards those with the greatest impact potential in energy consumption.

The proposed method makes it possible to identify behaviours with a richer semantic context (differentiating going out to lunch from going out to a meeting, for example), which allows for greater clarity in identifying the incentives to be generated for each action detected. Moreover, by associating each behaviour with the effect on the target variable that is intended to be affected (in this case, energy consumption) we can identify the behaviours whose change is most effective, thus reducing the potential to generate contradictory incentives.

In the specific case under study, which aimed to identify the behaviours related to the energy consumption of users in office buildings, five of the actions studied were identified that users usually perform and that can be subject to behavioural change, thus generating a reduction in energy consumption. In this sense, a direct implication of this methodology of identifying behaviours that could be changed was relevant for the design of a gamified mobile application aimed at reducing energy consumption in offices.

Thus, we can conclude that this method seems promising in obtaining behaviours that aim to be changed by a certain goal.

A limitation of this work was the fact that it was only applied in a single office context. Behaviours can differ from other offices, and indeed different in wildly different contexts such as residential dwellings. Another limitation concerns the heuristic approach to triangulation of data to identify choreographies. There lies potential in extracting choreographies in a more systematic manner, to lessen bias and reveal unexpected behaviours that observers may disregard. Although the presented method could be applicable to wider cases, there is also a limitation in terms of other energy related behaviours that could arise, due to the fact that only the consumption of computers and office lights were analysed.

The representation of virtual choreographies could have been better exploited through the use of ontologies or other computational formats, e.g. xAPI. This would, for example, enable the creation of a visual demonstrator to present the typified choreographies for richer human input on choreography identification. On the other hand, it would help in how the identified behaviours fit into a behavioural change platform or appliance.

As future work, considering that the basis that allowed the identification of the behaviours is sustained on the direct observation of the use case, it will be relevant to be able to advance with other methodologies that allow identifying choreographies related to the topic to be studied without resorting to direct observation. Given that, sometimes, situations may occur that such methodology is not possible to be applied.

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