EnerGAware
Energy Game for Awareness of energy efficiency in social housing communities

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D5.1 – Monitoring and evaluation methodology

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Executive summary

This report represents Deliverable 5.1 – Monitoring and evaluation methodology, developed as part of Work Package 5 – Monitoring and evaluation of the EnerGAware project.

The monitoring and evaluation methodology describes the longitudinal, three-stage experimental design, employing both pre-post and control group approaches that will be used in the EnerGAware project to test the effects of the EnerGAware serious game intervention in a UK social housing pilot.

The dependent (energy consumption, energy consumption behaviours and awareness, peak demand, social media activity, energy knowledge sharing and IT literacy) and independent variables (socio-economic status and health, energy price, perceived physical comfort, usability and usefulness and game interaction) that will be used to evaluate the effects of the EnerGAware serious game intervention are described.

For each dependent and independent variable the data that needs to be collected, from what households (experimental and/or control group) and at what resolution is outlined. In addition, the method for collecting the data is described, as well as, at what stage(s) in the experimental design the data needs to be collected.

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Glossary and abbreviations

DECC	Department of Energy and Climate Change
Dependent variable	The variable that is the target of an intervention and therefore shall be affected by the intervention.
ESI	Energy Saving Intervention
European ICT PSP	Methodology for calculating energy savings in buildings
Gross impact	The gross impact is the effect that is resulting from the intervention and other external influences (independent variables), general external aspects and design effects resulting from the instruments used for data collection.
HDD	Heating Degree Days
Independent variable	An independent variable is a factor that can also have an impact on the dependent variables. Independent variables are not part of the intervention and can have confounding effects that are unwanted if the effect resulting solely from the intervention shall be identified with the evaluation.
Intervention	An intervention is an action from outside, which has been undertaken and shall be evaluated. Within the context of the EnerGAware project, the intervention is a serious game given to social housing tenants to reduce energy consumption at home. As the EnerGAware project is also evaluating behaviour-related effects, the term intervention is also sometimes referred to as a treatment. The term originates from the psychological experiments which are used to identify cause and effect of measures, instruments etc. The main characteristic of experiments is the availability of two groups – the experimental or treatment group which receives the intervention and the control group which does not.
IPMVP	International Performance Measurement and Verification Protocol
Net impact	The net impact is the effect resulting solely from the intervention.
SUS	System Usability Scale
UK	United Kingdom

1. Introduction

This report represents Deliverable 5.1 – Monitoring and evaluation methodology, developed as part of Work Package 5 – Monitoring and evaluation of the EnerGAware project.

The monitoring and evaluation methodology defines the experimental design, as well as the dependent and independent variables that will be used to assess the effects of the EnerGAware serious game intervention deployed in the UK social housing pilot.

Firstly, the longitudinal, three-stage experimental design, employing both pre-post and control group approaches that will be used in the EnerGAware project is outlined.

Secondly, the dependent (energy consumption, energy consumption behaviours and awareness, peak demand, social media activity, energy knowledge sharing and IT literacy) and independent variables (socio-economic status and health, energy price, perceived physical comfort, usability and usefulness and game interaction) that will be used to evaluate the effects of the EnerGAware serious game intervention are described. Dependent variable is described as the variable that is the target of an intervention and therefore shall be affected by the intervention. An independent variable is a factor that can also have an impact on the dependent variables. Independent variables are not part of the intervention and can have confounding effects that are unwanted if the effect resulting solely from the intervention shall be identified with the evaluation. For each dependent and independent variable the data that needs to be collected, from what households (experimental and/or control group) and at what resolution is outlined. In addition, the method for collecting the data is described, as well as, at what stage(s) in the experimental design the data needs to be collected.

2. Longitudinal three-stage experimental design

The EnerGAware project will evaluate the change in a range of dependent variables as a result of the implementation of the EnerGAware serious game. The EnerGAware serious game is a proposed Energy Saving Intervention (ESI), the effects of which will be evaluated in a social housing pilot in the United Kingdom (UK).

However, the energy savings achieved from the introduction of an ESI cannot be measured directly, as it represents the difference between energy actually consumed after the intervention and that which would have been consumed had the intervention not been undertaken. As energy saving cannot be measured directly, any measurement is in fact based on an assumption of a

possible parallel development – the development of energy use without the intervention (i.e. non-intervention consumption).

The International Performance Measurement and Verification Protocol (IPMVP) (Efficiency Valuation Organisation, 2012), which is the basis of the common European ICT PSP Methodology for calculating energy savings in buildings (BECA project, 2012), suggests four possible methods for establishing the non-intervention consumption: option A (retrofit isolation: key parameter measurement), option B (retrofit isolation: all parameter measurement), option C (whole facility), option D (calibrated simulation). Three of these methods cannot normally be applied for domestic buildings (i.e. the focus of the EnerGAware project): an assumption of constant demand (Option A), cyclical predictable demand (Option B) and another demand structure which can be fully modelled (Option D), and therefore Option C is normally adopted in such cases, which does not assume constant energy demand or that demand variation can be accurately modelled.

The IPMVP approach in Option C, pre-post comparison (Section 2.1), will be applied in the EnerGAware project. In addition, a control group approach will be also implemented following the recommendation in ICT PSP Methodology (Section 2.2). This is in line with best practice in research methodology and evaluation across scientific disciplines.

2.1 Pre-post comparisons

In the pre-post comparison approach recommended in IPMVP Option C, the effect of an Energy Saving Intervention (ESI) is estimated through comparison of measured dependent variables before (baseline period) and after the intervention starts (reporting period).

In the EnerGAware project a longitudinal three-stage experimental design will be used in which the dependent variables will be measured and compared for an experimental group of 50 social houses during three time periods: before the intervention (baseline evaluation), after the intervention starts (mid-term evaluation) and at the end of the intervention (final evaluation). This will allow the project to assess both the short-term and longer term effects of the ESI.

In order to better understand the effects of the ESI on the dependent variables observed, information on a range of independent variables will also be collected during the baseline and reporting periods.

In the EnerGAware project, both the baseline and reporting period will cover one year (or at least, one heating period). A one year period captures all common variations in both dependent and independent variables and therefore an average effect can be calculated which could reasonably be expected to be repeated in future.

Figure 1 shows the pre-post comparison approach that will be used in the EnerGAware project.

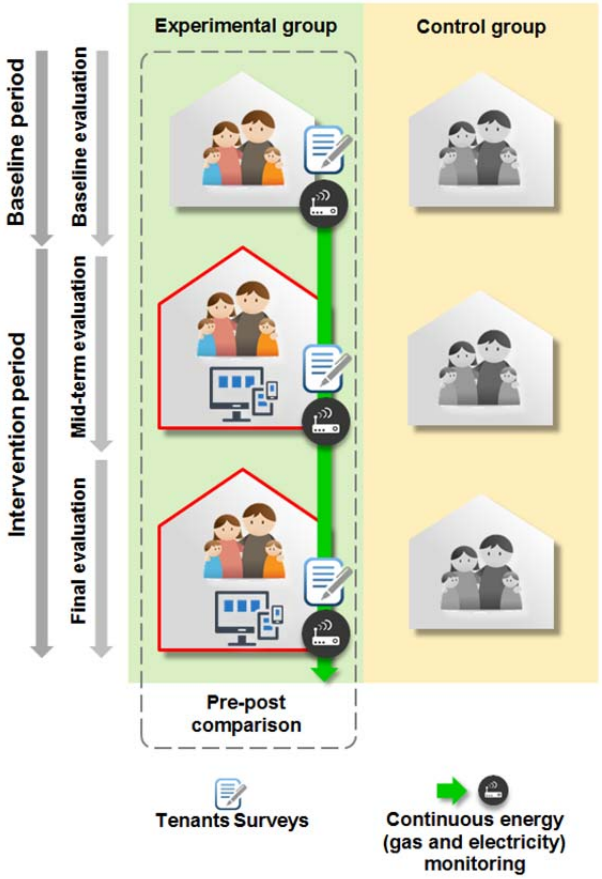

Figure 1. Pre-post comparison approach recommended in IPMVP Option C

2.2 Comparison with control group

In the control group approach recommended in the ICT PSP Methodology, changes in the dependent variables are examined for two groups of social houses, an experimental group with the ESI and a control group without. In the EnerGAware project, 50 social houses will be assigned to both the experimental and control group, with a total of 100 houses partaking in the pilot.

An advantage of the control group approach is that the data are collected over the same time period for both the experimental and control group; therefore both groups experience other external influences (e.g. energy price changes, longer school holidays, sports events, etc.) which could have an effect on the measured dependent variables. These external influences in the pre-post design could invalidate the results obtained, if they only occur in either the baseline or reporting period.

In an ideal situation, the social houses assigned to both the experimental and control groups would be identical, in terms of socio-demographic and dwelling characteristics, and the only difference between the groups would be the presence or absence of the ESI. Achieving identical experimental and control groups is common in other fields, such as medical control trials, however for applied built environment and energy projects, practical considerations will usually prevent the rigorous application of these standards.

In the EnerGAware project, the 100 social houses will be assigned to either the experimental or control group using a pairing approach, in which two identical/near-identical houses will be identified and one randomly assigned to each group. As the experimental and control group sample sizes are relatively small and there may be some unavoidable variations between the two groups, the effects of the ESI on the dependent variables will also be assessed in the context of a range of independent variables collected for each of the houses.

Figure 2 shows the control group approach that will be used in the EnerGAware project.

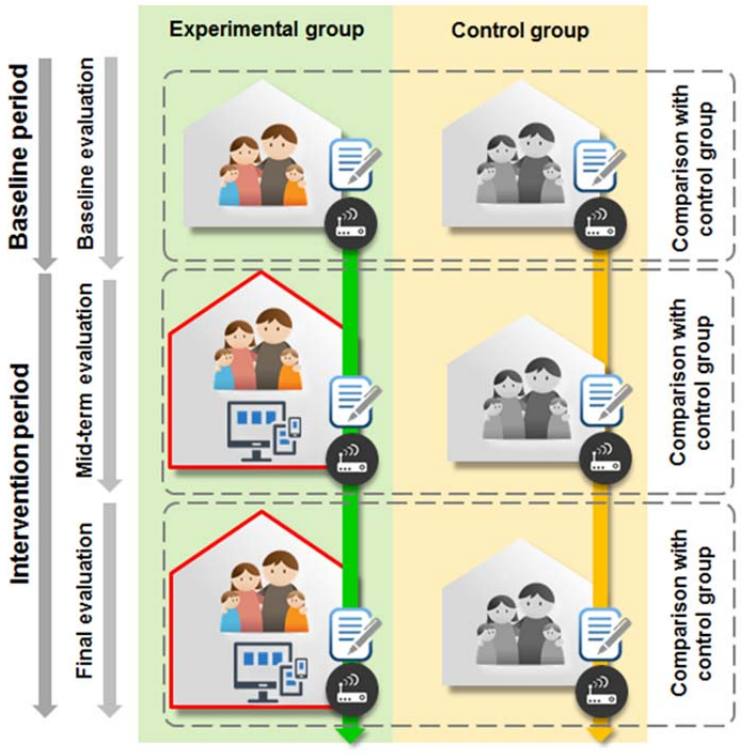

Figure 2. Control group approach recommended in ICT PSP Methodology

3.Dependent variables

The following dependent variables will be evaluated in the EnerGAware project: energy consumption, energy consumption behaviours and awareness, peak demand, social media activity, energy knowledge sharing and IT literacy. These variables are the target of the intervention (the EnerGAware serious game) and are therefore expected to be affected as a result of the intervention. The following sections describe the data that need to be collected, from what households (experimental and/or control group) and at what resolution for each key dependent variable. Furthermore, the method for collecting the data is outlined, as well as, at what stage(s) in the experimental design (i.e. baseline, mid-term or final evaluation) the data need to be collected.

At the time of writing this deliverable, the data needed for the baseline evaluation of the dependent variables related to Energy consumption behaviours and energy awareness (Section 3.2), and IT literacy (Section 3.4), had already been collected by means of the Social Housing Survey (Deliverable 2.1). This data was collected for both Experimental and Control groups. These variables are identified in Table 9.

At the time of writing this deliverable, the data requested for the baseline evaluation of energy-related dependent variables, i.e. Energy consumption (Sections 3.1) and Peak demand (Section 3.3), had not been collected yet. Energy-related data depend on the deployment of the energy monitoring system, which is planned for November 2015. This data will be collected for both Experimental and Control groups.

3.1 Energy consumption

The effect of the EnerGAware serious game intervention in terms of energy saving and emissions reductions will be evaluated by:

- Energy consumption reduction in the experimental group in relation to the baseline ($\overline{ECR_{exp\ baseline}}$)
- Energy consumption reduction in the experimental group in relation to the control group ($ECR_{exp\ ctrl}$)

Option C (whole facility) of the International Performance Measurement and Verification Protocol (IPMVP) (Efficiency Valuation Organisation, 2012) will be used. Total energy consumption (both gas and electricity) of the pilot homes will be measured throughout both the baseline and the reporting period by means of continuous measurements taken by an energy monitoring system deployed in the homes. In the event that continuous measurements are not possible due to the particularities of

the energy meters in some homes, either manual meter readings (Efficiency Valuation Organisation, 2012) or energy billing data will be used.

3.1.1 Energy consumption reduction in the experimental group in relation to the baseline

The **"Energy consumption reduction in the experimental group in relation to the baseline"** will be calculated as the average of the individual energy consumption savings (both electricity consumption and gas consumption when applicable) of all the social houses in the experimental group (i.e. those participating in the pilot and playing with the EnerGAware serious game) in relation to their combined average baseline consumptions.

The individual energy consumption reduction of a social house (*i*) in the experimental group in relation to their baseline, $ECR_{exp\ baseline\ i}$, is calculated using $C_{exp\ reporting\ i}$, which stands for the total energy consumed in household *i* in the experimental group during the reporting period expressed in kWh and $C_{exp\ baseline\ i}$, *which* represents the total energy consumed in household *i* in the experimental group during the baseline period expressed in kWh. According to the IPMVP the adjustments term in equation 1 is used to express both pieces of measured energy under the same set of conditions.

$$\boldsymbol{ECR_{exp\ baseline\ i}}\ [\%] = \frac{\boldsymbol{C_{exp\ reporting\ i} - C_{exp\ baseline\ i} \pm Adjustment_i}}{\boldsymbol{C_{exp\ baseline\ i}}} \cdot \mathbf{100} \qquad [1]$$

According to the IPMVP the baseline period should cover a whole year (or at least, one heating period) in order to account for all operating modes of the house and variations in weather conditions. In addition, the reporting period will also cover one year (or at least, one heating period) to account for a minimum of one normal operating cycle and to fully assess the impact of the ESI (EnerGAware serious game) on the energy consumption of the pilot house.

As stated by the IPMVP, adjustments in equation 1 may include energy-governing factors expected to routinely change during the reporting period such as the weather (routine adjustments) or energy-governing factors that are not expected to change during the reporting period such as the size, design and operation of installed equipment, type of occupants (non-routine adjustments).

Regarding routine adjustments and according to the European ICT PSP Methodology for calculating energy savings in buildings (BECA project, 2012), weather changes are the main reason of variability in the residential consumption profiles. Taking into account that energy consumption is predominantly heating related in the UK, weather-correcting energy consumption figures are based on Heating Degree Days (HDD). HDDs are a measure of the amount of time when the

outside temperature falls below the base temperature (when the building needs heating). HDD can be calculated for a certain period of time according to equation 2 as the addition of the difference between a base temperature and the outdoor temperature, when the outdoor temperature is lower than the base temperature:

$$\boldsymbol{HDD_{base} = \sum_1^n (T_{base} - T_{outdoor})\ if\ T_{base} < T_{outdoor}} \quad [2]$$

where T_{base} is the outdoor temperature above which the building needs heating, $T_{outdoor}$ is the outdoor temperature.

The base temperature used to calculate degree days in the UK is 15.5ºC, because at this temperature most UK buildings do not need supplementary heating (Carbon Trust, 2012).

The adjustment term accounts for phenomena such as a colder or warmer winter in the reporting period compared to the baseline period. If temperature adjustments are not taken into account, a colder winter during the reporting period could result in a higher consumption, hiding potential energy savings due to the EnerGAware serious game intervention. The adjustment will be calculated as follows:

$$\boldsymbol{Adjustment_i = a_i \cdot (HDD_{reporting} - HDD_{baseline})} \quad [3]$$

Where a_i is a parameter obtained after a linear regression of consumptions against HDD, $HDD_{reporting}$ are the Heating Degree Days calculated according to equation 2 for the reporting period and $HDD_{baseline}$ are the Heating Degree Days calculated according to equation 2 for the baseline period. a_i parameter is calculated for each household once during the baseline period using the last complete monthly values, after removing odd data (data quality filtering).

In this case, non-routine adjustments are not taken into account as they are not expected to change between the baseline and the reporting period.

The **"Energy consumption reduction in the experimental group in relation to the baseline"** ($\overline{ECR_{exp\ baseline}}$) indicator is calculated as the average individual energy consumption reduction of all the social houses in the experimental group in relation to their baseline according to equation 4 .

$$\boldsymbol{\overline{ECR_{exp\ baseline}} = \sum_{i=0}^{n} \frac{ECR_{exp\ baseline\ i}}{N_{exp}}} \quad [4]$$

Where $ECR_{exp\ baseline\ i}$ is the energy consumption reduction for each of the households *i* in the experimental group (those playing with the game) in relation to their baseline expressed as a

percentage (calculated using equation 1) and N_{exp} stands for the number of households playing with the game.

3.1.2 Energy consumption reduction in the experimental group in relation to the control group

The **"Energy consumption reduction in the experimental group in relation to the control group"** (*ECR exp ctrl*) indicator will be calculated according to equation 5.

$$\boldsymbol{ECR_{exp\ ctrl}}\ [\%] = \frac{C_{\text{exp } reporting} - C_{ctrl\ reporting}}{C_{ctrl\ reporting}} \cdot \mathbf{100} \qquad [5]$$

Where the $ECR_{exp\ ctrl}$ represents the energy consumption reduction of all the social houses in the experimental group (i.e. those participating in the pilot and playing with the EnerGAware serious game) in relation to the control group expressed as a percentage, the $C_{exp\ reporting}$ stands for the total energy consumed by the households of the experimental group during the reporting period expressed in kWh and $C_{ctrl\ reporting}$ represents the total energy consumed by the households of the control group during the reporting period expressed in kWh.

In case of comparison with control group and taking into account that the weather will have the same influence in the experimental and the control group, HDD will not be considered. In this case, the energy consumption highly depends on the floor area and the occupancy. For this reason, the energy consumed by all the households in the experimental group during the reporting period ($C_{exp\ reporting}$) is expressed in kWh/(m²·occupant) and calculated according to equation 6 aggregating the energy consumed by each household i in the experimental group during the reporting period ($C_{exp\ reporting\ i}$) corrected by the corresponding S_i (floor area of the household i in the experimental group expressed in m²) and N_i (the number of occupants of the household i in the experimental group)

$$C_{\text{exp}\,reporting} = \sum_{i=0}^{n} \frac{C_{exp\ reporting\ i}}{S_i \cdot N_i} \qquad [6]$$

The energy consumed by all the households in the control group during the reporting period ($C_{ctrl\ reporting}$) is also normalized and expressed in kWh/(m²·occupant):

$$C_{\text{ctrl}\,reporting} = \sum_{i=0}^{n} \frac{C_{ctrl\ reporting\ i}}{S_i \cdot N_i} \qquad [7]$$

Where $C_{ctrl\ reporting\ I}$ represents the energy consumed by each household i in the control group during the reporting period corrected by the corresponding S_i (floor area of the household i in the

control group expressed in m^2) and N_i (the number of occupants of the household i in the control group).

Energy saving will be calculated for each household in a daily basis. HDD and thus, daily outdoor temperatures, will be also measured, recorded and calculated in a daily basis.

Table 1. Energy consumption reduction

Energy consumption reduction
Method: Continuous measurement by smart meter sensors attached to the electricity and gas meters. Manual meter reading in homes where it is not possible to connect a smart meter sensor.
Participants: Experimental and control group
Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation: — Energy consumption (both gas and electricity) of each household every 15 minutes (kWh or m3 or ft3). — Outdoor temperature of the pilot location every 15 minutes for HDD normalisation (ºC).
Evaluation method: — Energy consumption reduction in the experimental group in relation to the baseline and control group

3.2 Energy consumption behaviours and energy awareness

Energy consumption behaviours and energy awareness will be assessed by comparing data collected by means of various items included in the Social Housing Survey (Deliverable 2.1) over the different stages of the experimental design (baseline, mid-term and final evaluation), and in both the experimental and control group.

The items included in the Social Housing Survey used to measure energy consumption behaviours and energy awareness are:

- Self-report assessment of current energy consumption behaviours (based on Matthies et al. (2011) and Abrahamse et al. (2007)), including self-reported space heating behaviour.
- Energy awareness, measured by items on: energy understanding, perceived control over energy use (based on Thøgersen & Grønhøj, 2010) and social norms (explicit or unspoken rules indicating how people should or ought to use/save electricity).
- Self-report measure of perceived fuel poverty.

As previously mentioned, at the time of writing this deliverable, the data needed for the baseline evaluation of the dependent variables related to Energy consumption behaviours and energy awareness had already been collected by means of the Social Housing Survey (Deliverable 2.1). This data was collected for both Experimental and Control groups. A tailored version of the Social Housing Survey, which will include only those items relevant to the evaluation methodology, will be used for the mid-term and final evaluations.

In addition to the Social Housing Survey questions, two new items related to fuel poverty will be collected and added to the rest of the baseline data, before the end of the baseline period. These will help to further assess the social housing tenants' perceived fuel poverty.

Table 2. Energy consumption behaviours and energy awareness

Energy consumption behaviours and energy awareness
Method: Survey For the Baseline evaluation stage: Items already included in Social Housing Survey. For the Mid-term and Final evaluation stages: Tailored version of the Social Housing Survey, which will include the items below.
Participants: Experimental and control group
Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation (gathered by means of the following items): <u>Energy consumption behaviours</u> — How often do you take the following actions? —— I make sure that the curtains/blinds are closed when the heating is on in the evening

- I make sure that the curtains are open when the sun is shining in winter
- I make sure that the windows are closed when the heating is on
- I change the temperature on my thermostat
- I adjust the temperature on my radiators
- I try to minimise my shower time to 5 minutes
- I make sure that no appliances are left on standby
- I make sure that chargers are unplugged when not in use
- I shut down my computer when it is not in use
- I only boil the water I need in the kettle
- I make sure that I use the right sized hob ring for each pan when cooking
- I make sure that the fridge and freezer doors are not open for longer than necessary
- When no one is at home the heating is off
- When I am the last to leave a room I turn the lights off
- I wear very warm clothes in winter so I can keep the heating on low or off
- When I buy a new appliance I look carefully at the energy labels
- I turn off the heating in rooms that are not normally used
- I close the doors between rooms
- I only use my washing machine when I have a full load of washing
- When I am the last to leave a room I turn off the appliances that are on
- I only use my dishwasher when it is full
- I use energy saving modes on my appliances
- I tell other people to do things that save energy

Response scale: 1 (Always); 2 (Often); 3 (Sometimes); 4 (Very occasionally); 5 (Never); Not applicable.

- Have you ever changed your energy supplier?

Responses: Yes; No.

— Have you ever compared energy prices using a comparison website?

Responses: Yes; No.

— At what temperature do you normally set your thermostat to during the winter? (For example 21ºC)

Responses: Specify number; Don't know; Not applicable

— At what level do you normally set your living room radiator to during the winter? (For example 3)

Responses: Specify number; Don't know; Not applicable

— At what level do you normally set your main bedroom radiator to during the winter? (For example 3)

Responses: Specify number; Don't know; Not applicable

— When do you normally have your heating on during a typical winter week day (Monday to Friday)? Use 24 hour clock (For example: ON 07:00, OFF 08:00, ON 18:00, OFF: 22:00)

Responses:

ON	OFF	ON	OFF	ON	OFF

All day ☐

— When do you normally have your heating on during a typical winter weekend day (Saturday and Sunday)? Use 24 hour clock (For example: ON 07:00, OFF 08:00, ON 18:00, OFF: 22:00)

Responses:

ON	OFF	ON	OFF	ON	OFF

All day ☐ Same as weekday ☐

— Generally speaking, during winter when heating needs are greatest, at which of these times are you or someone else in your household regularly at home? (Tick all that apply)

  — All day/all the time

  — Weekday morning (9am-12pm)

  — Weekday lunchtime (12pm-2pm)

  — Weekday afternoon (2pm-5pm)

  — Weekday evenings (after 5pm)

- Weekend daytimes
- Weekend evenings
- Highly variable
- Don't know

Energy awareness (Energy understanding, Perceived control over energy use, Social norm)

- How much do you agree or disagree with these statements?
  - I don't understand how my home uses energy
  - I am worried about my energy bills
  - I often think about how I could save energy
  - I have control over how much energy is consumed in my home
  - I am not able to save any more energy
  - I am prepared to save energy with the right support
  - My friends and family say it's important to save energy
  - I don't trust my energy supplier
  - I can easily imagine how much energy my home uses

Responses: 1(Strongly agree); 2 (Tend to agree); 3 (Neither agree nor disagree); 4 (Tend to disagree); 5 (Strongly disagree); Don't know.

Perceived fuel poverty

- How easy or difficult is it for you to afford your energy bills?

Responses: Very easy; Fairly easy; Neither easy nor difficult; Fairly difficult; Very difficult; Don't know

- Would you say you experience fuel poverty in your household? *

Responses: Yes; No; I don't know what fuel poverty is.

- How much money does your household tend to spend on energy and keeping warm in the home? *

Responses: 5% of my households' yearly income; 10% of my households' yearly income; 15% of my

households' yearly income; 20% of my households' yearly income; more than 20%.

** Items not included in the Social Housing Survey. These new items will be collected, and added to the rest of the baseline data, before the end of the baseline period.*

Evaluation method:

- Increased frequency of implementation of energy-efficient behaviour actions in the experimental group in relation to the baseline and control group.
- Change of behaviour towards changing and comparing energy suppliers in the experimental group in relation to the baseline and control group.
- Reduction of set point temperature and heating period in the experimental group in relation to the baseline and control group.
- Increased energy understanding and perceived control over energy use in the experimental group in relation to the baseline and control group.
- Increase perception of energy costs affordability in the experimental group in relation to the baseline and control group.

3.3 Peak demand

The effect of the EnerGAware serious game in terms of peak demand reduction will be evaluated as described below.

The peak demand reduction of each household in the experimental group in relation to their baseline will be calculated as:

- Individual peak demand reduction of each household in the experimental group in relation to the baseline ($PDR_{exp\ baseline\ i}$)
- Aggregated peak demand reduction in the experimental group in relation to the baseline during electricity network peaks ($PDR_{exp\ baseline\ NP}$)

The peak demand reduction of each household in the experimental group in relation to the control group will be evaluated by:

- Aggregated peak demand reduction in the experimental group in relation to the control group during electricity network peaks ($PDR_{exp\ ctrl\ NP}$)
- Aggregated peak demand reduction in the experimental group in relation to the control group ($PDR_{exp\ ctrl}$)

According to the European ICT PSP methodology for calculating energy savings in buildings (BECA project, 2012), the peak demand can be estimated through four methods including:

— Load factor reduction: the load factor is defined as the value obtained by dividing the minimum power demand of a building by its maximum power demand. The closer the load factor is to the value 1, the less the demand curve peaks. If the building load curve peaks correspond to the electricity network peaks, movement towards 1 can represent useful peak shaving.

$$\boldsymbol{Load\ Factor} = \frac{\boldsymbol{min}_{h=1\ldots24}\, \boldsymbol{P(t,h)}}{\boldsymbol{max}_{h=1\ldots24}\, \boldsymbol{P(t,h)}} \quad [8]$$

— Baseline profile model (10 day time model): baseline profile models are used to estimate the shaving peaks which occur unpredictably on particular days. A 10 day baseline model is produced from the 10 business days preceding the day in which peak shaving is assessed (reporting day). Actual consumption is compared between the baseline model and reporting day to quantify peak shaving.

$$\boldsymbol{p_1(t,h)} = \frac{\boldsymbol{1}}{\boldsymbol{10}} \sum_{\boldsymbol{i=1}}^{\boldsymbol{10}} \boldsymbol{p(t-i,h)} \quad [9]$$

— Baseline profile model (top 3 of 10 day model): as above but the baseline model is produced averaging the 3 highest consumption figures from the previous 10 business days to the reporting day.

$$\boldsymbol{p_2(t,h)} = \frac{\boldsymbol{1}}{\boldsymbol{3}} \cdot \big(\boldsymbol{p(i,h)} + \boldsymbol{p(j,h)} + \boldsymbol{p(k,h)}\big) \quad [10]$$

— Baseline profile model (top 3 of 10 day model with morning adjustment factor): as above, but an adjustment is added when the baseline is lower than the actual load in the morning on the day of the event.

$$\boldsymbol{p_3(t,h)} = \boldsymbol{p_2(t,h)} + \frac{\boldsymbol{1}}{\boldsymbol{2}} \cdot \big((\boldsymbol{p_2(t,h-1)} - (\boldsymbol{p(t,h-1)} + (\boldsymbol{p_2(t,h-2)} - (\boldsymbol{p(t,h-2)}\big) \quad [11]$$

As recommended in the European ICT PSP methodology for calculating energy savings in buildings, the load factor metric should not be used in projects addressing residential buildings (i.e. the target of the EnerGAware project). In residential buildings, identifying the minimum power demand can entail a significant error in case of unusual events such as electricity cuts or cleaning a fridge during a low demand period. These minimum power demands would lead to false load factor values and thus, to an inappropriate demand response assessment.

Therefore, baseline profile models will be used to identify peak demands in pilot social houses. A period of 10 (non-event) business days could reasonably be used in this project. However, this should be corroborated with real consumption data. When monitoring data reveals different consumption patterns during event days, the top 3 of 10 day model will be used.

3.3.1 Individual peak demand reduction of each household in the experimental group in relation to the baseline

The peak demand reduction of a social house (*i*) in the experimental group (playing with the EnerGAware serious game) in relation to their baseline ($PDR_{exp\ baseline\ i}$) is calculated through equation 12 using the $P_{exp\ reporting\ i}$, which stands for the peak demand of the household of the experimental group during the reporting period expressed in kW and the $P_{exp\ baseline\ i,}$ *which* represents the peak demand of the same household during the baseline period expressed in kW.

$$\mathbf{PDR_{exp\ baseline\ i}}\ [\%] = \frac{\mathbf{P_{exp\ reporting\ i} - P_{exp\ baseline\ i}}}{\mathbf{P_{exp\ baseline\ i}}} \cdot \mathbf{100} \qquad [12]$$

$P_{exp\ reporting\ i}$ and $P_{exp\ baseline\ i}$ *will be calculated according to equations* 9 or 10 taking into account the individual power demand when the individual peak takes place.

3.3.2 Aggregated peak demand reduction in the experimental group in relation to the baseline during the electricity network peaks

In order to analyse peak demands from the energy demand management side, the aggregated peak demand reduction during the electricity network peaks will also be explored. In this case, the **"Aggregated peak demand reduction in the experimental group in relation to the baseline during the electricity network peaks"** will be calculated according to equation 13.

$$\boldsymbol{PDR_{exp\ baseline\ NP}}\ [\%] = \frac{\boldsymbol{P_{exp\ reporting\ NP} - P_{exp\ baseline\ NP}}}{\boldsymbol{P_{exp\ baseline\ NP}}} \cdot \mathbf{100} \qquad [13]$$

Where the $PDR_{exp\ baseline\ NP}$ represents the peak demand reduction of all the social houses in the experimental group in relation to their baseline during the electricity network peak expressed as a percentage, the $P_{exp\ reporting\ NP}$ stands for the peak demand of all the households of the experimental group during the reporting period when the electricity network peak takes place expressed in kW and $P_{exp\ baseline\ NP}$ represents the peak demand of all the households of the experimental group during the baseline period when the electricity network peak takes place expressed in kW.

$P_{exp\ reporting\ NP}$ and $P_{exp\ baseline\ NP}$ *will be calculated according to equations* 9 or 10 taking into account the global power demand when the network peak takes place.

3.3.3 Aggregated peak demand reduction in the experimental group in relation to the control group during the electricity network peaks

In order to analyse peak demands from the energy demand management side, the aggregated peak demand reduction during the electricity network peaks will also be explored. In this case, the **"Aggregated peak demand reduction in the experimental group in relation to the control group during the electricity network peaks"** will be calculated as the average individual peak demand reduction of all the social houses in the experimental group in relation to control group during the electricity network peaks according to equation 14.

$$\boldsymbol{PDR_{exp\ ctrl\ NP}}\ [\%] = \frac{\boldsymbol{P_{\exp\ reporting\ NP}} - \boldsymbol{P_{ctrl\ reporting\ NP}}}{\boldsymbol{P_{ctrl\ reporting\ NP}}} \cdot \mathbf{100} \qquad [14]$$

Where the $PDR_{exp\ ctrl\ NP}$ represents the peak demand reduction of all the social houses in the experimental group in relation to the control group during the electricity network peak expressed as a percentage, the $P_{exp\ reporting\ NP}$ stands for the peak demand of all the households of the experimental group during the reporting period when the electricity network peak takes place expressed in kW and $P_{ctrl\ reporting\ NP}$ represents the peak demand of all the households of the control group during the reporting period when the electricity network peak takes place expressed in kW.

$P_{exp\ reporting\ NP}$ and $P_{ctrl\ reporting\ NP}$ *will be calculated according to equations* 9 or 10 taking into account the aggregated power demand when the network peak takes place.

3.3.4 Aggregated peak demand reduction in the experimental group in relation to the control group

In order to analyse peak demands from the building facilities' perspective and to avoid simply displacing the peak, the **"Aggregated peak demand reduction in the experimental group in relation to the control group"** (*$PDR_{exp\ ctrl}$*) will be calculated according to equation 15.

$$\boldsymbol{PDR_{exp\ ctrl}}\ [\%] = \frac{\boldsymbol{P_{\exp\ reporting}} - \boldsymbol{P_{ctrl\ reporting}}}{\boldsymbol{P_{ctrl\ reporting}}} \cdot \mathbf{100} \qquad [15]$$

Where the $PDR_{exp\ ctrl}$ represents the peak demand reduction of all the social houses in the experimental group in relation to the control group expressed as a percentage, the $P_{exp\ reporting}$ stands for the peak demand of the households of the experimental group during the reporting

period expressed in kW and $P_{ctrl\ reporting}$ represents the peak demand of the households of the control group during the reporting period expressed in kW.

$P_{exp\ reporting}$ and $P_{ctrl\ reporting}$ will be calculated according to equations 9 or 10 taking into account the global power demand when the individual peak takes place.

Table 3. Peak demand

Peak demand shaving
Method: Continuous measurement by smart meter sensor attached to the electricity meter
Participants: Experimental and control group
Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation: — Electricity consumption of each household every 15 minutes (kWh).
Evaluation method: — Individual peak demand reduction of each household in the experimental group in relation to the baseline — Aggregated peak demand reduction in the experimental group in relation to the baseline during the electricity network peaks — Aggregated peak demand reduction in the experimental group in relation to the control group during the electricity network peaks — Aggregated peak demand reduction in the experimental group in relation to the control group

3.4 Social media activity, energy knowledge sharing and IT literacy

Social media activity will be monitored at mid-term and final evaluation to assess social tenants' willingness to share energy saving strategies, knowledge and achievements from the EnerGAware serious game. Which information and data social tenants are willing to share and which information attracts attention and debate will be monitored qualitatively (e.g. comments in posts) and quantitatively (e.g. number of times a user posts or likes others posts). Social media activity and energy knowledge sharing will be monitored in the experimental group only.

IT literacy will be measured by examining householders' confidence with using a computer and the internet. A survey will assess IT literacy at the baseline, mid-term and final evaluation stage for the experimental and control group.

Table 4. Social media activity, energy knowledge sharing, and IT literacy

Social media activity and energy knowledge sharing
Method: Qualitative and quantitative monitoring of social media activity (Manual monitoring) *Automatic quantification of the number of times a user posts or likes others posts will be explored.*
Participants: Experimental group
Stage(s) of experimental design: Mid-term and final evaluation
Data requested for the evaluation: Frequency — Number of times a user posts comments or content in social media related to the game or energy topics. — Number of times a user likes others posts related to the game or energy topics. Content — Content of social media activities analysed in terms of the energy saving strategies, knowledge and achievements related to the EnerGAware serious game.
Evaluation method: — Level of social media activity related to energy-related content and game features.
IT literacy
Method: Survey For the Baseline evaluation stage: Items already included in Social Housing Survey. For the Mid-term and Final evaluation stages: A tailored version of the Social Housing Survey, which will include the items below.
Participants: Experimental and control group

Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation (gathered by means of the following items): IT literacy *How much do you agree or disagree with these statements?* — I feel confident using a computer — I feel confident using the Internet Responses: 1(Strongly agree); 2 (Tend to agree); 3 (Neither agree nor disagree); 4 (Tend to disagree); 5 (Strongly disagree); Not applicable.
Evaluation method: — Increased confidence using a computer in the experimental group in relation to the baseline and control group. — Increased confidence using the internet in the experimental group in relation to the baseline and control group.

4. Independent variables

In the EnerGAware project a number of independent variables will also be assessed: socio-economic status, health, energy price, perceived physical comfort, usability and usefulness and game interaction.

An independent variable is a factor that can also have an impact on the dependent variables. Independent variables are not part of the intervention and can have confounding effects that are unwanted if the effect resulting solely from the intervention is desired in the evaluation. It is important to measure the independent variables in order to identify the net impact of an intervention, not only the gross impact.

The following sections describe the data that need to be collected, from what households (experimental and/or control group) and at what resolution for each independent variable. Furthermore, the method for collecting the data is outlined, as well as, at what stage(s) in the experimental design (i.e. baseline, mid-term or final evaluation) the data need to be collected.

At the time of writing this deliverable, the data needed for the baseline evaluation of some of the independent variables had already been collected by means of the Social Housing Survey

(Deliverable 2.1). These include: Socio-economic status and Health (Section 4.1) and Perceived physical comfort (Section 4.3). This data was collected for both Experimental and Control groups. These variables are identified in Table 9.

It is worth noting that the variables related to use of the EnerGAware serious game, i.e. Usability and Usefulness (Section 4.4) and Game interaction (Section 4.5), do not require baseline evaluation, as they depend on the deployment of the serious game in the pilot homes.

4.1 Socio-economic status and health

At each stage of the evaluation process a survey will collect data on the socio-economic status and physical and mental health of the social housing tenants in the experimental and control group. This will allow us to keep track of any changes in the household and the potential influences on the key outcomes. As previously mentioned, the data required for the baseline evaluation has already been collected by means of the Social Housing Tenant Survey.

Table 5. Socio-economic status and health

Socio-economic status and health
Method: Survey For the Baseline evaluation stage: Items already included in Social Housing Survey. For the Mid-term and Final evaluation stages: Tailored version of the Social Housing Survey, which will include the items below.
Participants: Experimental and control group
Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation (gathered by means of the following items): <u>Age and gender</u> — How old are you? Responses: Specify Age; Prefer not to answer. — I am... Responses: Male; Female; Prefer not to answer.

Employment and education

— What is your employment status?

Responses: Employed; Unemployed; Seeking work; Student; Retired; Other (please specify); Prefer not to answer.

— Do you have any educational qualifications for which you received a certificate?

Responses: Yes; No; Prefer not to answer.

— Do you have any professional, vocational or other work-related qualifications for which you received a certificate?

Responses: Yes; No; Prefer not to answer.

— What is you highest qualification?

Responses: O'level, GCSE, NVQ level 2 or equivalent; A'Level, NVQ level 3 or equivalent; Degree level (e.g., BA, BSc) or above; Another kind of qualification; Not applicable; Prefer not to answer.

Household occupancy

— Who is living with you?

Responses:

	Adult (over 18 years)	Child (16-18 years)	Child (Under 16 years)	Male	Female
Person 1	☐	☐	☐	☐	☐
Person 2	☐	☐	☐	☐	☐
Person 3	☐	☐	☐	☐	☐
Person 4	☐	☐	☐	☐	☐
Person 5	☐	☐	☐	☐	☐

— How many people in your household are… (Insert number)

Responses:

Employed		Retired	
Unemployed		Other	
Seeking work		Prefer not to answer	
Student			

Health

— How was your health in general in the last 12 months?

Responses: 1(Very good); 2 (Good); 3 (Fair); 4 (Bad); 5 (Very bad).

— How many times have you visited your GP surgery in the last 12 months?

Responses: Specify number; Prefer not to answer.

— Overall, how satisfied are you with life nowadays?

Responses: 1(Not at all satisfied) 2 3 4 5 6 7 8 9 10 (Completely satisfied).

4.2 Energy price

Changes to the price of energy will be tracked during all stages of the experimental design (baseline, mid-term and final evaluation). The quarterly percentage change in energy prices for all domestic fuels will be obtained from secondary data provided by the UK Government's Department of Energy and Climate Change (DECC) Quarterly Energy Prices Report available online at: https://www.gov.uk/government/collections/domestic-energy-prices

Energy price
Method: Secondary data from DECC's Quarterly Energy Prices Report
Participants: Experimental and control group
Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation: — Quarterly percentage change in energy price for all domestic fuels (electricity and gas)

4.3 Perceived physical comfort

The participants' physical perceptions of comfort will be assessed using a survey at the baseline, mid-term and final evaluation stage. The data about physical perceptions of comfort will be collected from the experimental and control group. As previously mentioned, the data required for the baseline evaluation has already been collected by means of the Social Housing Tenant Survey.

Table 6. Perceived physical comfort

Perceived Physical Comfort
Method: Survey For the Baseline evaluation stage: Items already included in Social Housing Survey. For the Mid-term and Final evaluation stages: Tailored version of the Social Housing Survey, which

will include the items below.
Participants: Experimental and control group
Stage(s) of experimental design: Baseline, mid-term and final evaluation
Data requested for the evaluation (gathered by means of the following items): — During the cold winter weather, can you normally keep comfortably warm in your living room? Responses: Yes; Yes, but it costs a lot; No; Don't know; Not applicable. — If you cannot keep comfortably warm in your living room in winter, is this because… Responses: It costs too much to keep the heating on; It is not possible to heat my home to a comfortable temperature; Don't know; Other reason (please explain); Not applicable. — During the warm summer weather, do you sometimes feel too hot in your living room? Responses: Yes; No; Don't know; Not applicable. — During the warm summer weather, do you sometimes feel too hot in your bedroom when you are going to sleep? Responses: Yes; No; Don't know; Not applicable.

4.4 Usability and usefulness

The participants will be asked to assess the perceived usability and usefulness of the EnerGAware serious game. The data on usability and usefulness of the EnerGAware serious game will be collected by survey from the experimental group only at the mid-term and final evaluation stage.

The usability refers to the ease with which the social tenants can interact with, and understand the serious game, to efficiently achieve their desired goals and actions, so it is focussed on the user specific experiences of operation of the serious game. It will be assessed with the System Usability Scale (SUS), a ten-item scale providing a global view of subjective usability (Brooke, 1996). Using the SUS a usability score can be calculated, representing the overall usability of the system being studied. A score of 68 or higher is considered an above average usability score.

The usefulness refers to the social tenants' perceptions of the advantages of using the serious game compared to their prior situation (before deployment of the serious game). It will be assessed by asking the social tenants to report on the things they have learned from interacting with the EnerGAware serious game.

Table 7. Usability and usefulness

Usability and Usefulness
Method: Survey
Participants: Experimental group only
Stage(s) of experimental design: Mid-term and final evaluation stage
Data requested for the evaluation (gathered by means of the items such as): Usability (*SUS scale)* — I think that I would like to use the EnerGAware serious game frequently — I thought the EnerGAware serious game was easy to use — I felt very confident using the EnerGAware serious game — I needed to learn a lot of things before I could get going with the EnerGAware serious game Responses: 1(Strongly disagree) 2 3 4 5 (Strongly agree) Usefulness — The EnerGAware serious game was helpful in identifying ways to reduce my energy bills — The EnerGAware serious game has taught me something new — The EnerGAware serious game has helped me pinpoint specific actions I can take to save energy Responses: 1(Strongly disagree) 2 3 4 5 (Strongly agree) — How much did you like the following features of the EnerGAware serious game? — The energy saving game — The Real-time energy data about my home — The virtual rewards for saving energy in the game — The virtual rewards for saving energy in my home — The social media features Response scale: 1 2 3 4 5 (Where 1 is A lot and 5 Not at all)

4.5 Game interaction

Information related to how users interact with the actual game system and the components of it and with other players (in-game behaviour) will be recorded by the game infrastructure automatically by means of gameplay metrics.

Gameplay metrics will assess the level of user interaction with the game on the other dependent variables, such as energy consumption reduction or energy awareness.

They will also provide the opportunity to identify how players address key questions, if they use game features as intended, and whether they find any barriers hindering their progression. Other metrics will include the number of times the game is played by each user, how often, time of the day and the average gameplay time.

Table 8. Game interaction

Game interaction
Method: Game user analytics automatically recorded by the game infrastructure
Participants: Experimental group only
Stage(s) of experimental design: Mid-term and final evaluation stage
Data requested for the evaluation (gathered by means of items such as): — Number of connections per day/week: check the daily/weekly log-in actions — Duration of each connection: Average time of connection per day/week — Idle or active in game: check the actions in game — In game “mission” progress — Unlocked features or “mission” — What was the last “mission” the user did complete? — What were the last actions done by the user? — Frequency connection — Content access — Does the user read the message?: Time appearance on screen

- Does the user skip the message?: Skip button / close message
- Does the user look forward for additional information?: Activation button to reach the additional content

- Number of actions: Actions by user VS all the available actions
- Number of trophies or completed missions: Per day / week
- Number of shared information:
  - Success and trophies
  - Comments

5. Conclusions

This report represents Deliverable 5.1 – Monitoring and evaluation methodology, developed as part of Work Package 5 – Monitoring and evaluation of the EnerGAware project.

The monitoring and evaluation methodology defines the experimental design, as well as the dependent and independent variables that will be used to assess the effects of the EnerGAware serious game intervention deployed in the UK social housing pilot.

The report has outlined the longitudinal, three-stage experimental design, employing both pre-post and control group approaches that will be used in the EnerGAware project. This approach will not only assess the impact of the EnerGAware serious game over time and compared to a control group, but will also account for other potentially influential factors.

Moreover, the 15 variables that will be used to evaluate the effects of the EnerGAware serious game intervention have been described. These variables consist of 8 dependent variables and 7 independent variables. For each dependent and independent variable the data that needs to be collected, from what households (experimental and/or control group) and at what resolution has been outlined. In addition, the method for collecting the data has been described, as well as, at what stage(s) in the experimental design the data needs to be collected. A summary of the variables and the stages of the experimental design when they will be collected for each group is presented in Table 9.

Table 9. Summary of variables.

VARIABLES	DATA COLLECTION METHOD	EXPERIMENTAL / CONTROL GROUP	Baseline evaluation	Mid-term evaluation	Final evaluation
Energy consumption (3.1)	Energy monitoring Outdoor temperature monitoirng	Experimental group	X	X	X
		Control group	X	X	X
Energy consumption behaviours and energy awareness (3.2)	Tenant Survey	Experimental group	√	X	X
		Control group	√	X	X
Peak demand (3.3)	Energy monitoring	Experimental group	X	X	X
		Control group	X	X	X
Social media activity (3.4) **Energy knowledge sharing (3.4)**	Social media analytics	Experimental group		X	X
		Control group			
IT literacy (3.4)	Tenant Survey	Experimental group	√	X	X
		Control group	√	X	X
Socio-economic status (4.1) **Health (4.1)**	Tenant Survey	Experimental group	√	X	X
		Control group	√	X	X
Energy price (4.2)	Secondary data of quarterly energy price	Experimental group	X	X	X
		Control group	X	X	X
Perceived physical comfort (4.3)	Tenant Survey	Experimental group	√	X	X
		Control group	√	X	X
Usability (4.4) **Usefulness (4.4)**	Tenant Survey	Experimental group		X	X
		Control group			
Game interaction (4.5)	Game user analytics	Experimental group		X	X
		Control group			

Note1: The period where the EnerGAware serious game is deployed in the experimental group households is highlighted in green.

Note2: √ = Data already collected at the time of the Deliverable writing; **X** = Data to be collected; **Cells not selected** = Data not needed for the evaluation methodology designed.

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