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Project Title:

New Buildings Energy Renovation Business Models incorporating dual energy services

NOVICE

Grant Agreement No: 745594

Collaborative Project

D6.1 Report on Performance Metrics Calculations

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No & name	**Task 6.3 Estimation of performance metrics**				
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Author(s)	Christof Amann, Andreea Le Cam, Jo Southernwood, Rosie Creedon				
Description of the related task and the deliverable in the DoA	A set of performance metrics will be defined to evaluate the success of dual energy services model in building renovation. Those are going to include both energy efficiency and demand response. Using the data from T6.2 those performance metrics will be calculated for the duration of the monitoring campaign. Those metrics will also include the assessment of thermal comfort post renovation and elaborate on gender aspects on comfort perception.				

V	Date	Authors	Description
0.1	09/01/2020	Andreea Le Cam	First draft of sections
1.0	29/05/2020	Christof Amann	Final version

EXECUTIVE SUMMARY

The objective of this report is to define and describe a set of performance metrics that evaluate the success of the NOVICE dual energy services business model. The performance metrics will cover the two parts of the project, respectively the energy efficiency and the demand response portion. It will also include comfort metrics.

The aim of the NOVICE project has been to develop and demonstrate a new business model for Energy Services Companies (ESCOs) in building retrofit that would improve the business case for Energy Performance Contracts (EPC). By considering the flexibility potential of the onsite energy assets during the design of the building renovations, this business model has the potential to provide energy efficiency savings to buildings and demand response services to the grid, thus creating a dual revenue stream that can reduce the payback period of the building renovation as a whole. In order to validate the business model, the NOVICE project team have attempted to apply these ideas at suitable demonstration sites.

Originally, it was planned to implement demonstration projects with the NOVICE dual service model and monitor the performance for a representative period of time. Despite of the huge efforts of the consortium and several promising projects, no project could be implemented in real life. Alternatively, in this report the archetypes selected for the calculation of the revenue streams from the NOVICE dual energy services business model, a case study from a retail site in Kilkenny and a simulated demand response event in a leisure centre in Dublin were used for the data presentation and analysis.

For the modelled and simulated archetypes, consisting of large hotels, large offices and hospitals, energy efficiency performance improvements are displayed and compared. For demand response, a simple strategy was selected. The only asset offered for the flexibility market was the chiller, switched off for 15, 30, 60 and 120 minutes. Potential demand response loads are analysed for all archetypes in different markets (Spain, Austria, Ireland) and for different times of the year (winter, summer). As demand response events are likely to effect comfort parameters, it was assessed, how indoor temperature will change after switching off the chiller. Depending on the building and the climatic zone, duration of the demand response event must not exceed 30 minutes or 1 hour.

The Kilkenny case study focused on the implementation of energy efficiency improvement measures, including batteries and EV chargers, the assessment of switching from fossil fuels towards renewable energy sources and offering flexibility to the grid. Energy efficiency performance and demand response performance metrics, including benchmark data, are presented and discussed.

For the last case study, a leisure centre in Dublin, a demand response event was simulated. Effects of the 2-hour event on perceived comfort were documented with a small survey. Even though in some areas metered data detected changes in temperature, humidity and CO_2, there was only little to no effect on perceived comfort.

Depending on the particular project, relevant metrics look different. This is especially true for demand response, where metrics have to be adapted to specific market conditions and to the distinction between incentive-based (explicit) demand response and prize-based (implicit) demand response. Even though there is a set of commonly used metrics for all three domains, developed projects will have to look for the very specific framework conditions and requirements. This will result in the need for tailormade performance metrics.

CONTENTS

1 INTRODUCTION

1.1 NOVICE IN BRIEF

The aim of the NOVICE project has been to develop and demonstrate a new business model for Energy Services Companies (ESCOs) in building retrofit that would improve the business case for Energy Performance Contracts (EPC). By considering the flexibility potential of the onsite energy assets during the design of the building renovations, this business model has the potential to provide energy efficiency savings to buildings and demand response services to the grid, thus creating a dual revenue stream that can reduce the payback period of the building renovation as a whole. This could drive market uptake of the EPC model in Europe, making it more attractive to building owners and investors. In order to validate the business model, the NOVICE project team have attempted to apply these ideas at suitable demonstration sites. For the purpose of this report, the NOVICE business model is also referred to as the 'NOVICE dual services' model.

1.2 OBJECTIVE OF THE REPORT

The objective of the report is to define and describe a set of performance metrics that evaluate the success of the NOVICE dual energy services business model. The performance metrics will cover the two parts of the project, respectively the energy efficiency and the demand response portion.

The report will specifically discuss whether combining the demand response and energy efficiency will have a considerable impact on the thermal comfort of occupants and will analyse how thermal comfort is perceived by the two genders.

Originally, it was planned to implement demonstration projects with the NOVICE dual service model and monitor the performance for a representative period of time. Despite of the huge efforts of the consortium and several promising projects, no project could be implemented in real life. Alternatively, in this report the archetypes selected for the calculation of the revenues from the NOVICE dual energy services model, a case study from a retail site in Kilkenny and a simulated demand response event in a leisure centre in Dublin will be used for the data presentation and analysis.

2 PARAMETERS AND PERFORMANCE METRICS FOR THE NOVICE DUAL ENERGY SERVICES BUSINESS MODEL

For the selection and assessment of buildings appropriate for the NOVICE dual energy services business model and for the operation of the buildings, a set of parameters and performance metrics need to be defined. These metrics are related to energy efficiency as well as demand response. Additionally, comfort issues have to be considered as well, however, in a very broad understanding of comfort.

Performance metrics do not only include quantitative but also quantitative parameters necessary to select and assess buildings for the implementation of energy efficiency improvement and demand response measures.

2.1 Overview of Parameters and Performance Metrics

Name		Description
General parameters of the building	• Type of the building • Floor area (total) • Floor area (per use area: retail, storage, dwelling, …) • Floor area (conditioned) • No of floors • Construction period • Technical status • Number of permanent occupants (staff and residents) and clients • …	General parameters help to generally qualify buildings or type of buildings for further steps like energy audits, technical status assessment etc.
Technical equipment	• Type of energy supply (central heating, district heating, single flat heating, …) • On-site production of energy (CHP, PV, …) • HVAC equipment (incl. power, age, technical status) • Metering and available sensors • Other equipment (EV chargers, appliances, …)	Technical equipment of buildings (including date of installation) determine possible solutions for energy efficiency measures as well as for demand response strategies.
Energy efficiency parameters	• Energy consumption, subdivided in electricity, heat, other energy carriers (natural gas, heating oil, biomass, …) • Energy production (PV, CHP, …) • Benchmark data (energy consumption per floor area, energy consumption per production unit, energy consumption per staff member, …)	Energy data should be available for at least one year, ideally on a 15 minutes basis (electricity) or monthly basis (gas or fuel oil, biomass). Energy data – in conjunction with general characteristics – will be used for definition of the energy baseline for (M&V)
Energy cost data	• Tariffs for electricity, gas, fuel oil, biomass etc. • Structure of tariffs (fixed elements, variable elements, taxes, …)	Energy bills from previous years and actual energy delivery contract
Demand response parameters	• Switchable loads • Power of CHP • Storages (hot water, electricity, …)	Size of switchable loads/production units is the main metrics for demand response; usually this will be determined after an energy audit.
Operation of buildings	• Availability and type of BEMS • Benchmarks • Facility management (FM) (in house or external)	Availability of BEMS and FM are decisive for the implementation of energy efficiency and demand response measures

Energy performance	• Energy performance certificate • Comparison of actual energy efficiency data with baseline and benchmarks	EPC and demand response require an agreement on the baseline according to international M&V standards like IPMVP
Demand response performance	• Documentation of demand response events	
Comfort parameters	• Range of indoor air (per zone) • Range of relative humidity (per zone) • Maximum of CO_2	Comfort parameters have to be agreed in the EPC (incl. demand response) – NOVICE dual energy services model

Table 1: Overview on Performance Metrics

2.2 Selection of Buildings

For the selection of the demo sites in NOVICE, a more detailed list of criteria and information was prepared, attached in the Annex of this document. Background of this list is the fact that in most cases – as in the targeted demo site buildings – energy efficiency and demand response measures could have already been implemented effecting economic performance of future implementation of energy efficiency and demand response measures. This effect can be positive (i.e. increasing economic performance) in the case of demand response where necessary equipment is already installed and can be used for continuing or improving participation in programmes. It can also be negative (i.e. reducing economic performance) in the case of previous implementation of no or low-cost energy efficiency measures (so called "low hanging fruits") complicating the implementation of further measures.

This list includes energy data as well as demand response data and economic information. Ideally, the following data are available:

Energy efficiency measures

- List of all energy efficiency measures installed in the last 3 years
- Installation date for each energy efficiency measure
- Cost of installation of energy efficiency measures (breakdown in CAPEX and OPEX)
- Electricity consumption (15 minutes data for 12 months before and 12 months after installation of energy efficiency measures)
- Gas consumption (60 minutes data for 12 months before and 12 months after installation of energy efficiency measures)
- Oil/other fuel consumption (daily, weekly or monthly consumption)
- Electricity price (actual bill, including changes)
- Gas price (actual bill, including changes)
- Oil/other fuel price (actual invoice, including changes)
- Other site charges (beside energy)
- Funding source for the energy efficiency installations (breakdown: self funding, grants, loans, interest charges, terms, …)
- Incentives received (e.g. feed in tariffs, renewable heat incentives, capital allowances)

Demand and frequency response

- Demand response equipment installed
- Installation date of demand response equipment
- Cost of installed demand response equipment (breakdown in CAPEX and OPEX)
- List of demand response programmes
- Revenues from participation in demand response programmes (annually and/or per demand response event)
- Further details on demand response participation (number of dispatches per year, date/time of dispatches, revenue received from each dispatch, multiple years are beneficial)

Other information

- Indication on occupants' comfort (any measured data covering the period assessed)
- Site details (sector, building floor area, approximate location, approximate staff numbers, typical occupied hours, biggest energy consuming areas/equipment, changes in usage of facility before/after EE improvement)

3 DEFINITION OF PERFORMANCE METRICS

For renovation projects applying the energy performance contracting (EPC) approach, improvement of energy efficiency is the main goal. Simultaneously, agreed comfort parameters have to be maintained and certain characteristics will be improved (e.g. ventilation, light quality) according to users needs or regulation.

A few performance metrics will need to be evaluated, ideally for a period of at least one year before and after the energy efficiency renovation.

3.1 ENERGY EFFICIENCY PERFORMANCE METRICS

3.1.1 Energy consumption

Energy consumption is usually reported as annual figure. It can be further subdivided into energy consumption of different energy sources (electricity, natural gas, fuel oil, biomass, heat etc.). This is of high relevance when it comes to define energy efficiency measures for the EPC and for estimating the demand response potential. For experienced ESCOs and aggregators, absolute figures allow a first feasibility check for both, EPC and demand response.

Energy consumption can further be divided into different zones in buildings and in energy use categories (lighting, HVAC, appliances etc.).

Different to households, most medium and large consumers have (or can provide) data on their load curve on a 15 minutes solution. This still underrated data source allows a much better assessment of energy efficiency and demand response potential than annual data.

Any energy consumption will have to be adjusted for the ex post performance evaluation. This is done with the agreed M & V strategy and it usually includes data on climatic conditions, occupancy, production level etc.

3.1.2 Energy efficiency benchmarks

As energy efficiency is defined as a relation between energy used for a certain service, benchmarks help to rate buildings and assess energy efficiency potential as well as energy performance status and gains. The following benchmarks are most common and provide easy-to-compare figures.

- Energy consumption per floor area
- Energy consumption per conditioned floor area
- Energy consumption per occupant
- Energy consumption per production unit
- …

All these benchmarks can and should be further disaggregated into energy sources, energy uses etc. Typically in EPC, data are adjusted for different climatic conditions, occupancy, production level or any other agreed factor. This is done according to the M & V strategy.

3.2 Demand Response Performance Metrics

Demand response metrics need to be evaluated before, during and after the demand response event. Depending on the market where demand response is offered, different metrics have to be applied. Demand response can be divided in explicit (incentive-driven) and implicit (price-driven) demand response. While price-driven demand response aims to change consumption patterns according to price signals from the market (e.g. dynamic tariffs), in explicit demand response changes of loads are directly rewarded, either for the availability or for activation. In NOVICE, the focus was on the balancing market and therefore on explicit demand response. On the balancing market availability and activation is rewarded, depending on the specific product. All products on the balancing market have their own requirements, consisting of:

- Switchable power (kW)
- Duration of turn-off or turn-on (sec, min)
- Duration until full turn-off or turn-on (sec, min, hours)

These requirements have to be met by aggregators offering demand response towards the TSO, however, distributed assets will have to be able to provide necessary conditions.

The site’s performance in terms of demand response will be based on how much flexibility is available at a specified moment, if the site is capable of responding within the required period and for how long this state can be maintained. Ideally, all this has to be achieved without affecting comfort of the occupants beyond the accepted range.

It is equally important to take a look at the rebound effect after the demand response event has finished. This includes analysing how long it takes for the building to get back to normal indoor conditions and how much extra energy is required to bring the building to a normal state of operation. This might affect energy efficiency performance.

3.3 Comfort Metrics

Comfort parameters are important element in EPCs where energy efficiency improvements may not exceed agreed ranges of comfort. With the implementation of demand response strategies, this condition stays valid, however, it could be agreed to increase the level of accepted complaints or the number of hours where the comfort range may be exceeded. The main metrics for comfort are:

- Indoor air temperature
- Relative humidity
- CO2 level

All these parameters cannot only be affected by the contracted party and/or facility management but also from behaviour of occupants (e.g. opening the windows). This has to be considered in the extended EPC for the NOVICE dual energy services business model.

Turning down or turning on equipment to allow for flexibility is likely to change the indoor air quality, depending on how long the demand response event is and how long it takes for the building to get back to normal operating conditions. The indoor air performance metrics will be defined to establish what can be considered as an acceptable deviation from the normal operating conditions.

3.3.1 Indoor air temperature

It is important to verify that the indoor air temperature remains within acceptable values after the renovation is performed.

3.3.2 Relative humidity

Post renovation, the relative humidity should also stay within the recommended range for each type of building use.

3.3.3 CO_2 levels

The energy efficiency part of the project is considered successful if the CO_2 levels are under the recommended safe limit.

3.3.4 Gender aspects of comfort perception

There is good empirical evidence, that comfort perception is different for female and for male occupants. “Females are less satisfied with room temperatures than males, prefer higher room temperatures than males, and feel both uncomfortably cold and uncomfortably hot more often than males. Although females are more critical of their thermal environments, males use thermostats in households more often than females.” (Karjalainen, 2007)

The difference in thermal needs of females and males has been argued to be attributed to clothing differences (Karjalainen, 2012). The evidence to prove the difference between female and male thermal comfort comes mostly from field studies. Laboratory evidence of this is little. This means that evidence is anecdotal and perhaps circumstantial. Fanger (Fanger, 1970) found that women are more sensitive to fluctuations in thermal levels than men, but concluded that for identical clothing and activity, there were few gender differences in warmer conditions. However, women tended to be cooler than men in cool/colder conditions (van Hoof, 2008).

These differences have strong influence on energy efficiency performance and has to be considered in EPCs. Due to missing “real” demo projects, except for the leisure centre in Dublin, gender aspects could not be analysed further.

3.4 MEASUREMENT AND VERIFICATION (M & V)

Energy savings cannot be measured.

3.4.1 M & V in EPC

Energy savings cannot be measured directly but have to be calculated against a predefined and agreed baseline. This baseline is crucial for a correct (i.e. accepted and agreed by both the client and the ESCO) calculation of energy savings. For the calculation of the baseline and energy savings, international standards like IPMVP (International Performance Measurement and Verification Protocol, M&V; ISO 50 006 Energy Management - Measuring Energy Performance) are available and widely applied. In the M & V strategy adjustment parameters for changes in occupancy, outdoor temperature, used floor area, production level etc. are used to normalize baseline in order to compare baseline with measured energy data.

3.4.2 M & V in DR

Flexibility is defined as the ability to change loads as a result of external signals (query, price etc.). Similar to the assessment of energy savings, it is necessary to define a baseline against which power adjustment can be calculated. This is not only relevant for the correct calculation of revenues from control market but also compensation of the energy provider or the affected balancing responsible party (BRP). Methodology of M & V, however, has to be distinguished from energy efficiency savings calculations even though terms and approach are similar. The main question for M & V in flexibility is: What would have been the energy consumption, or the power, in the case that no demand response event happened. This is important not only for financial compensation of the parties involved but also for avoiding counterbalancing by the balancing responsible party of the energy supplier.

4 ARCHETYPES: OFFICE BUILDING, HOSPITAL, HOTEL

For 3 types of buildings, selected from an analysis of the European building stock and expected to be most suitable for the NOVICE dual energy services business model (archetypes), energy performance and demand response parameters were calculated, built on detailed simulations in different climatic conditions and markets (Spain, Austria, and Ireland). These buildings, the modelling and the calculation of revenues are described in D5.3/5.4 of NOVICE.

These selected buildings archetypes (Figure 1) are:

- Large Hotel
- Large Office Building
- Hospital

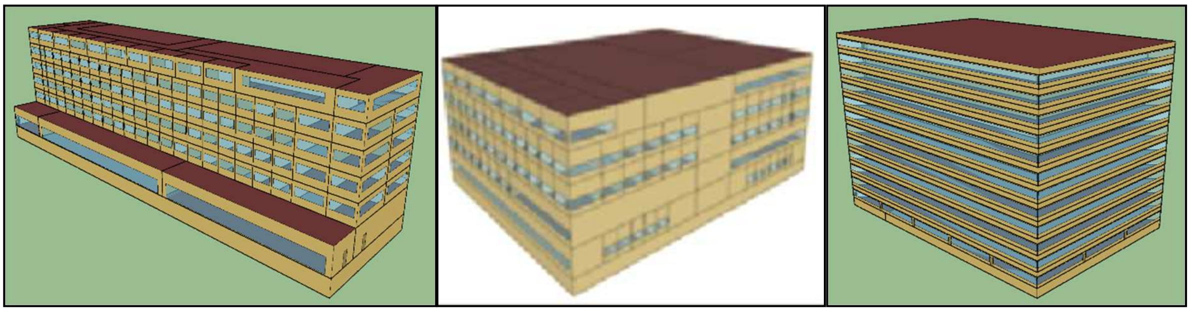

Figure 1: Building Archetypes (Source: DOE)

In order to secure indoor conditions after the implementation of demand response strategies, comfort parameters were simulated. Demand response strategies consisted of switching off the chiller for 15, 30, 60 and 120 minutes. Effects of energy consumption on a 5 minutes basis and on comfort parameters (temperature) were modelled for all archetypes, all climates and all markets.

4.1 Energy Efficiency Performance Metrics

In this chapter we give an overview on highly aggregated energy efficiency improvements in different countries. Energy consumption includes electricity and natural gas. Energy audits necessary to prepare EPCs usually provide much more detailed data disaggregated by energy carrier, end use and with a high solution in time (ideally 15 minutes).

Large office buildings

	Spain	Austria	Ireland
Conditioned building area	46 320 sqm	46 320 sqm	46 320 sqm
Energy consumption before renovation	8 774 MWh	10 206 MWh	9 618 MWh
… per sqm conditioned **floor area**	189 kWh/sqm	220 kWh/sqm	208 kWh/sqm
Energy consumption after renovation	7 289 MWh	8 819 MWh	8 256 MWh
… per sqm conditioned **floor area**	157 kWh/sqm	190 kWh/sqm	178 kWh/sqm
Energy efficiency improvement	-17%	-14%	-14%

Table 2: Energy Efficiency Performance Metrics for Large Office Buildings

Hospitals

	Spain	Austria	Ireland
Conditioned building area	18 697 sqm	18 697 sqm	18 697 sqm
Energy consumption before renovation	12 894 MWh	13 882 MWh	13 750 MWh
… per sqm conditioned floor area	690 kWh/sqm	743 kWh/sqm	735 kWh/sqm
Energy consumption after renovation	10 408 MWh	11 364 MWh	11 227 MWh
… per sqm conditioned floor area	557 kWh/sqm	608 kWh/sqm	601 kWh/sqm
Energy efficiency improvement	-19%	-18%	-18%

Table 3: Energy Efficiency Performance Metrics for Hospitals

Large Hotels

	Spain	Austria	Ireland
Conditioned building area	11 345 sqm	11 345 sqm	11 345 sqm
Energy consumption before renovation	6 170 MWh	6 764 MWh	6 306 MWh
… per sqm conditioned floor area	544 kWh/sqm	596 kWh/sqm	556 kWh/sqm
Energy consumption after renovation	5 388 MWh	6 198 MWh	5 881 MWh
… per sqm conditioned floor area	475 kWh/sqm	546 kWh/sqm	518 kWh/sqm
Energy efficiency improvement	-13%	-8%	-7%

Table 4: Energy Efficiency Performance Metrics for Large Hotels

Depending on the type of building and the country, energy efficiency improvement was 7 to 19%. This rather low value is a result of the selected renovation strategy, where only broadly applied energy efficiency measures were implemented. In practice, energy efficiency gains are expected to be larger as a result of a thorough energy audit and the selection of more specific energy efficiency measures.

4.2 Demand Response Performance Metrics[1]

Energy profiles were modelled for all building types in different markets and climates. Only turn-down events (switch-off of chillers) were considered. This was done for 4, 8 and 12 a.m. as well as for 4 and 8 p.m. with a duration of 15 min, 1 hour and 2 hours. In order to consider different physical behaviour of the buildings during the year, modelling of Demand Response (DR) events was carried out for summer and winter season. Depending on the season and the duration of the DR event, switchable load was calculated. Rebound effect was estimated as well.

As an example, energy profiles of a hospital in Ireland are presented. Energy consumption is significantly larger in summer as are the switchable loads.

[1] This chapter is mainly taken from Amann et al. 2020

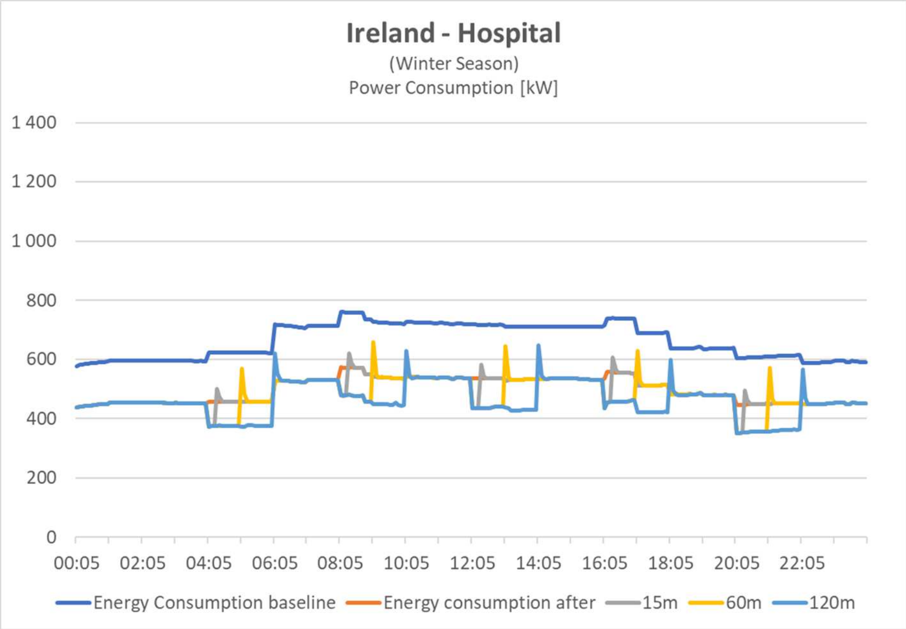

Table 5: Energy Profile with DR Events in a Hospital in Ireland (Winter)

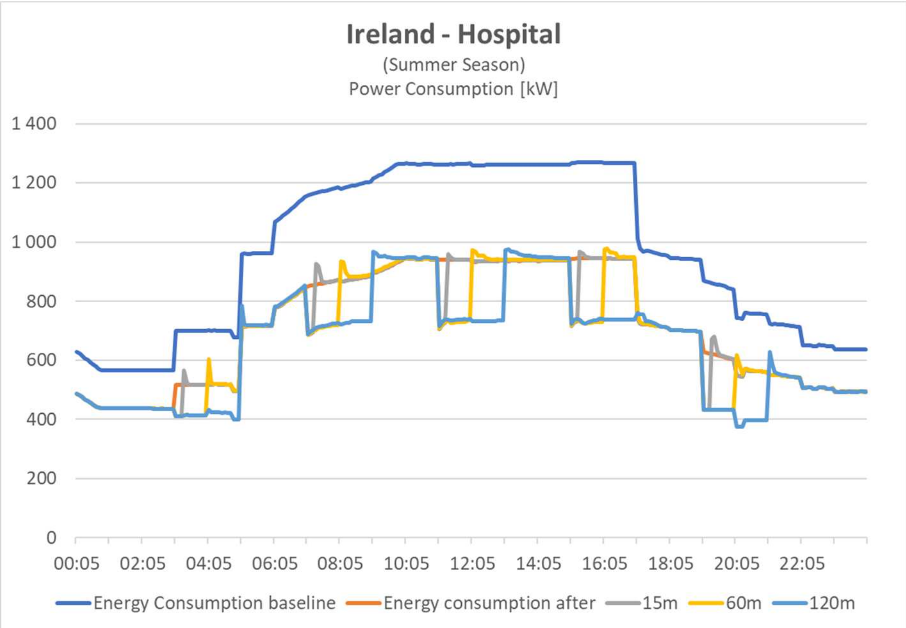

Table 6: Energy Profile with DR Events in a Hospital in Ireland (Winter)

In the following tables average switchable loads are documented. It is obvious that loads depend on the type of building, season, climate (IRL, AUT, ESP), and time during the day. Except for hospitals, switchable loads (chillers) are only available during certain periods of time. E.g. hotels and offices have no or only limited potential for shut-down in winter and shoulder season.

Ireland

	Winter	Shoulder	Summer
Time	[kW]	[kW]	[kW]
04:00	81	100	99
08:00	92	100	148
12:00	100	99	204
16:00	94	100	210
20:00	92	103	175

Table 7: Switchable Loads in Hospital (IRL)

	Winter	Shoulder	Summer
Time	[kW]	[kW]	[kW]
04:00	0	12	0
08:00	0	12	19
12:00	0	12	*)
16:00	0	12	*)
20:00	0	0	18

*Table 8: Switchable Loads in Hotel (IRL, *) switch-off is overcompensated by rebound effect within switching period)*

	Winter	Shoulder	Summer
Time	[kW]	[kW]	[kW]
04:00	0	44	0
08:00	0	84	86
12:00	0	86	131
16:00	0	86	87
20:00	0	0	180

Table 9: Switchable Loads in Office (IRL): average switchable load (2 hours)

Spain

	Winter	Shoulder	Summer
Time	[kW]	[kW]	[kW]
04:00	80	97	189
08:00	79	95	235
12:00	104	125	312
16:00	104	112	313
20:00	101	110	246

Table 10: Switchable Loads in Hospital (ESP)

Time	Winter [kW]	Shoulder [kW]	Summer [kW]
04:00	0	0	16
08:00	0	4	8
12:00	18	3	109
16:00	18	*)	127
20:00	11	9	72

*Table 11: Switchable Loads in Hotel (ESP, *) switch-off is overcompensated by rebound effect)*

Time	Winter [kW]	Shoulder [kW]	Summer [kW]
04:00	0	2	*)
08:00	0	26	316
12:00	36	112	556
16:00	24	123	532
20:00	32	0	401

*Table 12: Switchable Loads in Office (ESP, *) switch-off is overcompensated by rebound effect)*

Austria

Time	Winter [kW]	Shoulder [kW]	Summer [kW]
04:00	65	74	117
08:00	74	76	183
12:00	84	90	258
16:00	82	96	244
20:00	77	91	175

Table 13: Switchable Loads in Hospital (AUT)

Time	Winter [kW]	Shoulder [kW]	Summer [kW]
04:00	0	0	25
08:00	0	0	*)
12:00	0	11	22
16:00	0	8	30
20:00	0	0	8

*Table 14: Switchable Loads in Hotel (AUT, *) switch-off is overcompensated by rebound effect)*

	Winter	Shoulder	Summer
Time	[kW]	[kW]	[kW]
04:00	0	0	*)
08:00	0	0	13
12:00	0	0	234
16:00	0	0	188
20:00	0	0	57

*Table 15: Switchable Loads in Office (AUT, *) switch-off is overcompensated by rebound effect)*

With a few exceptions, hotels do not have any significant loads (> 50 kW). Office buildings have a clear dependency on the climate and time during the day. Switchable loads are high between 8 a.m. and 8 p.m. (12 a.m. and 4 p.m.) in summer and - to a lower extent - in shoulder season and more or less insignificant in winter.

From a demand response perspective, only hospitals can offer a significant amount of switchable loads during the whole year with a range from appr. 70 to 300 kW.

4.3 Comfort Metrics[2]

The NOVICE dual service model combines energy efficiency measures with demand response. Explicit demand response strategies such as turn-down events might reduce comfort conditions of the occupants. For this reason, an assessment of thermal comfort for the archetypes building is presented here.

The range of temperatures obtained in summer-day (worst-case) simulations for the three selected locations and for DR event durations of 15 minutes, 30 minutes, 1 hour and 2 hours are compared against the indoor set point temperature in hours of occupancy.

[2] This chapter is mainly taken from Amann et al. 2020

Hospital archetype

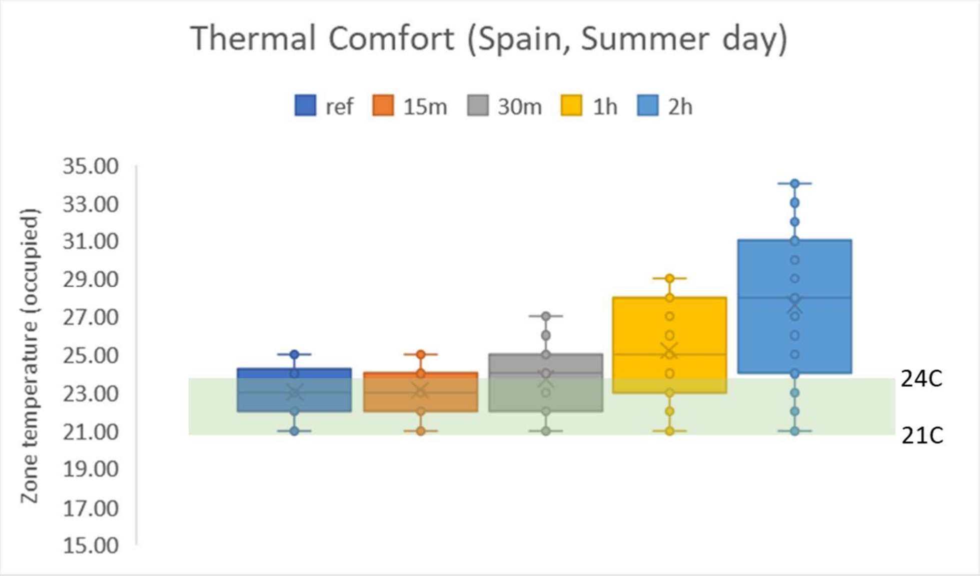

Figure 2: Thermal Comfort in Hospital (Spain, Summer Season)

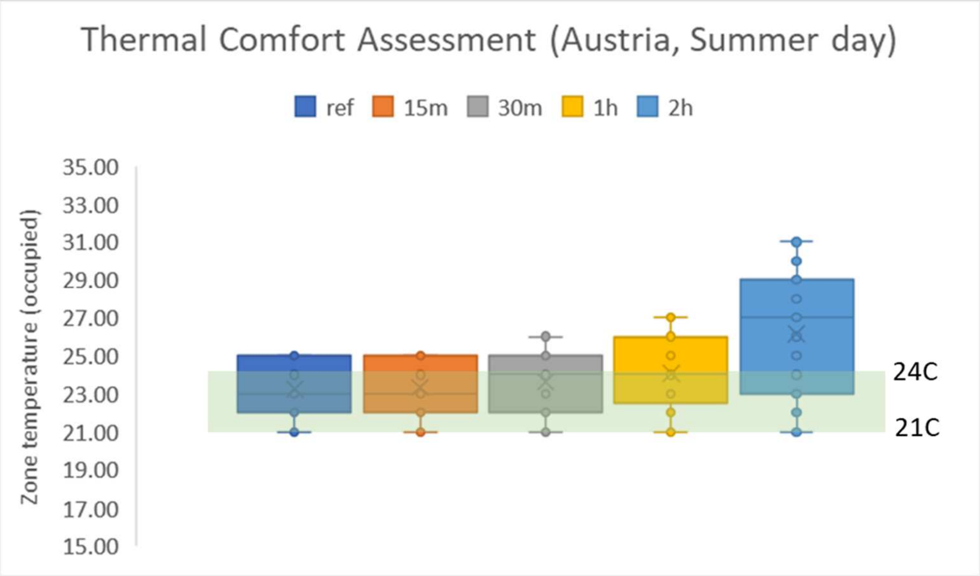

Figure 3: Thermal Comfort in Hospital (Austria, Summer Season)

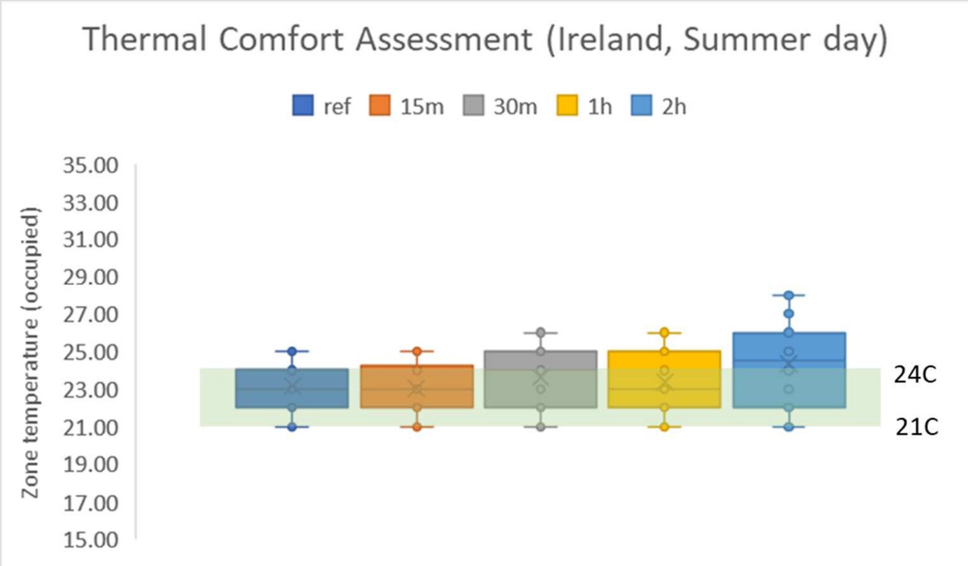

Figure 4: Thermal Comfort in Hospital (Ireland, Summer Season)

The results show that demand response events of durations of 30 minutes or less are within thermal comfort boundaries. They also show that for the climatic conditions of Dublin (Ireland) an event of up to one hour would also be possible since indoor temperature can be maintained approximately 85% of the time within comfort boundaries (21 to 24° C). For both the Austria and the Spain cases DR events of one hour and longer would significantly impact comfort conditions of occupants.

Office archetype

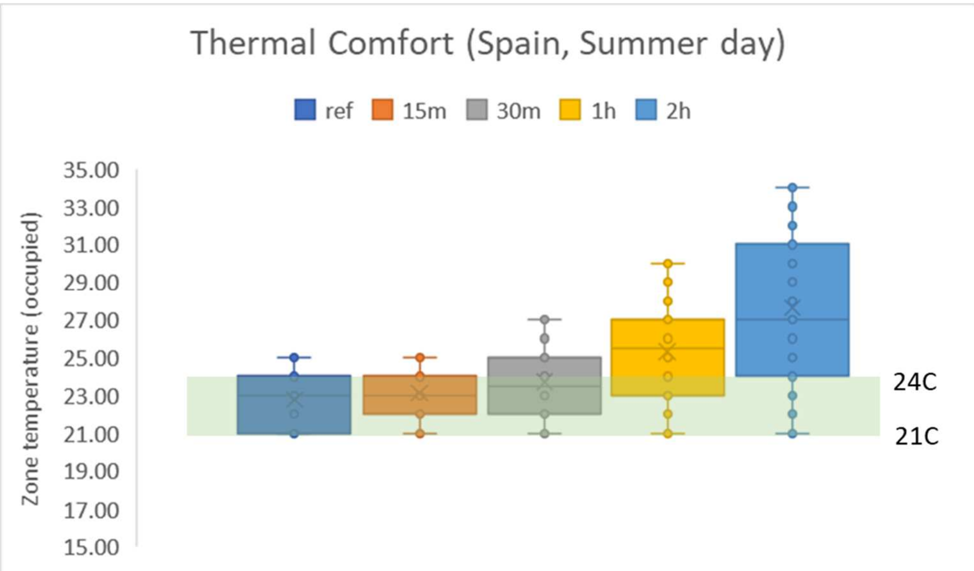

Figure 5: Thermal Comfort in Office (Spain, Summer Season)

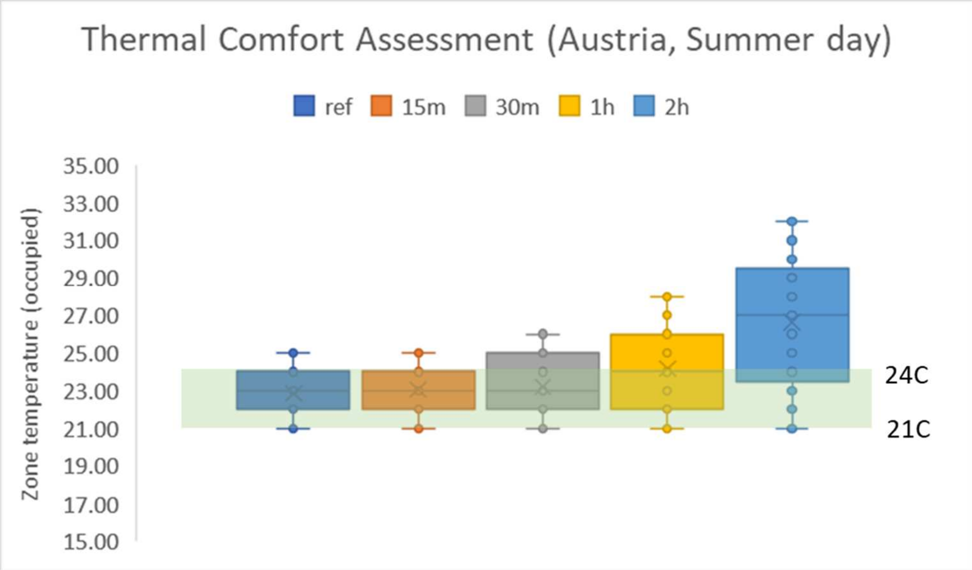

Figure 6: Thermal Comfort in Office (Austria, Summer Season)

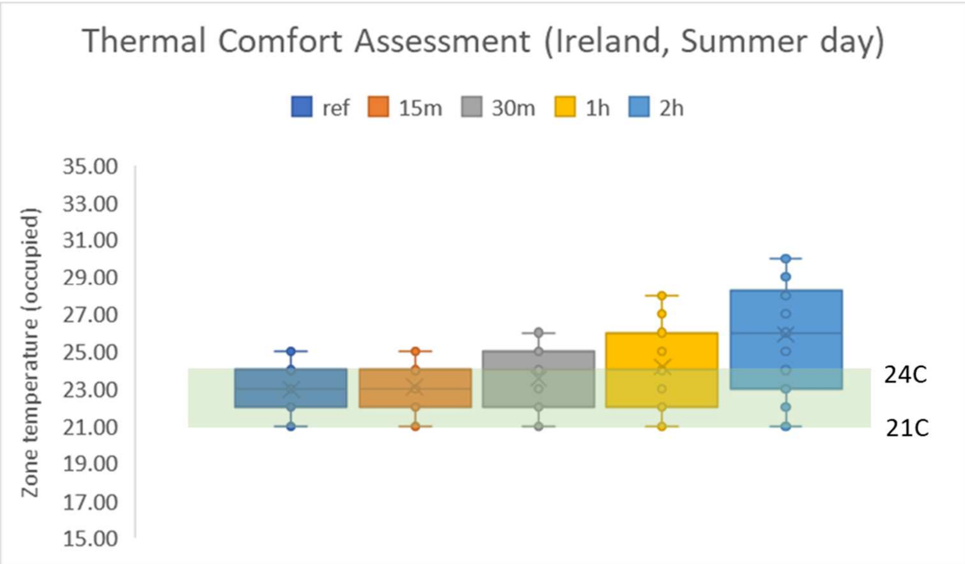

Figure 7: Thermal Comfort in Office (Ireland, Summer Season)

The results show that DR events of durations of 30 minutes or less are within thermal comfort boundaries, although this is not valid for meeting rooms where generally high internal loads are present.

Hotel archetype

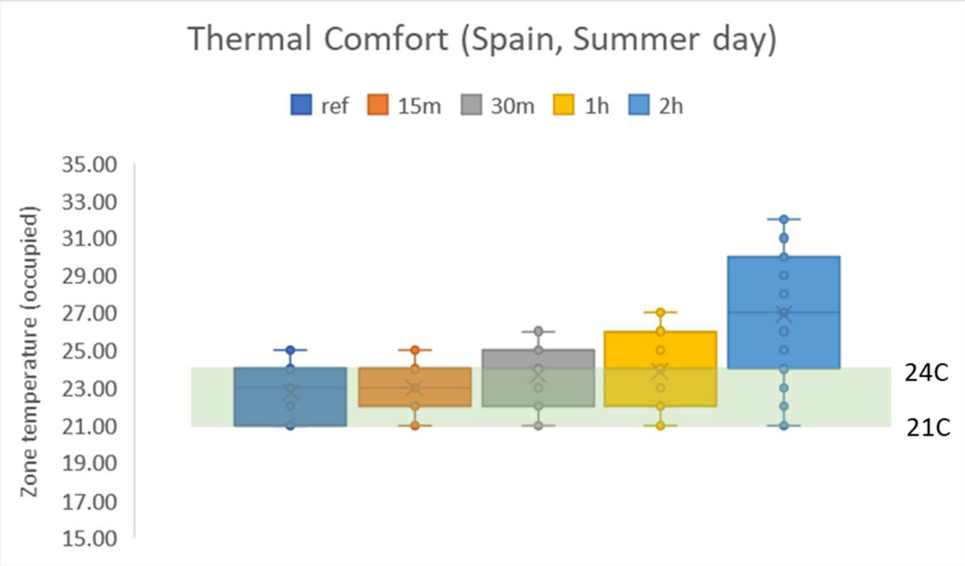

Figure 8: Thermal Comfort in Hotel (Spain, Summer Season)

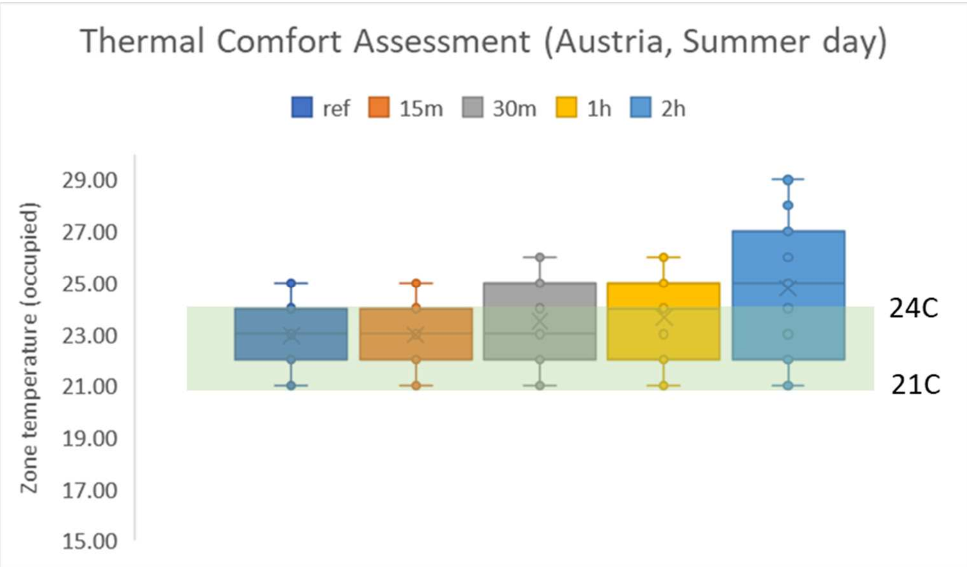

Figure 9: Thermal Comfort in Hotel (Austria, Summer Season)

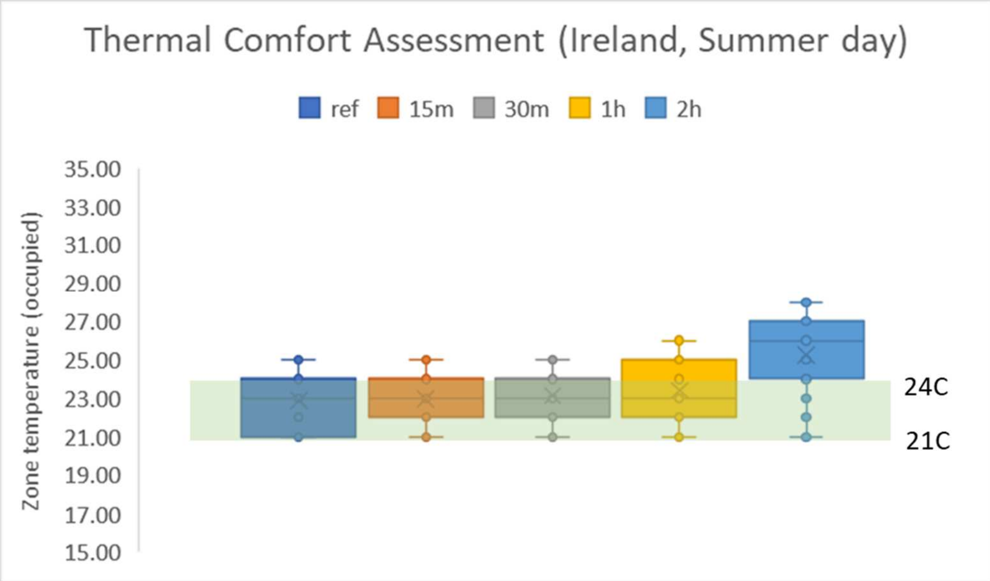

Figure 10: Thermal Comfort in Hotel (Ireland, Summer Season)

The results show that DR events of durations of 30 minutes or less are within thermal comfort boundaries. They also show that for the climatic conditions of Dublin (Ireland) and Vienna (Austria) events of up to one hour would also be possible since indoor temperature can be maintained approximately 85% of the time within comfort boundaries (21 to 24° Celsius). Here the occupancy profile of hotels, generally low in the hottest hours plays a role. DR events longer than one hour and 30 minutes for the case of Valencia (Spain) would significantly impact comfort conditions of the occupants.

5 Case Study: Supermarket, Kilkenny/IRL

Instead of a demo site where the NOVICE dual energy services business model is implemented, a case study was carried out for a supermarket in Kilkenny, Ireland, including energy efficiency improvement, integration of renewable energy and demand response. Numerous options have been assessed, including heat pumps, EV chargers and batteries. Due to long payback periods, upgrade of fabric was excluded from the case study. Carbon footprints and the effect of rising carbon taxes were included in the case study but are not considered here.

The cases study focuses on:

- Upgrade of refrigeration (mainly due to an obligation to move towards a more environmentally friendly refrigerant gas)
- Upgrade of lighting (LED upgrade, enhanced lighting quality)
- Upgrade of HVAC (efficient boilers, pumps, chillers, motors; hydraulic balancing; controls)
- Installation of PV
- Investigation of replacement of fossil fuels (heat pumps, use of biofuels, use of hydrogen)
- Investigation of heat recovery from refrigeration (preheating of DHW)
- Investigation of EV chargers

- Investigation of batteries
- Provision of grid services

5.1 Energy Efficiency Performance Metrics

The store in Kilkenny, Ireland, is divided into two main retail areas: textile (selling clothes and shoes) and grocery (selling food and drink). The area amounts to 4,347 m^2.

Total energy consumption is 2,670 MWh per year (2019), electricity accounts for 56%, and natural gas consumption accounts for the remaining 44%. Most of the electricity is consumed by lighting and refrigeration. The store's HVAC systems consumes less than half as much electricity as the refrigeration system (see

		Energy Consumption - Before (kWh)	Energy Consumption - After (kWh)	Reduction in Energy Consumption (%)
Electrical	Lighting	466,398	246,258	47%
	Refrigeration	443,540	110,885	75%
	HVAC	184,061	156,452	15%
	Other+Power	410,144	410,144	0%
	Electrical total	**1,504,143**	**923,739**	**39%**
	PV array *		-279,879	30%
Thermal	Space Heating	926,454	926,454	0%
	Heat recovery (DHW)	240,000	136,902	43%
	Heating total	**1,166,454**	**1,063,356**	**9%**
Total (el. Total + PV + heat. Total)		**2,670,597**	**1,707,216**	**36%**

Table 16).

Thermal energy (natural gas) is dominated by space heating, amounting to 926,454 kWh (79%), domestic hot water (DHW) amounts to 240,000 kWh, a share of 21%.

		Energy Consumption - Before (kWh)	Energy Consumption - After (kWh)	Reduction in Energy Consumption (%)
Electrical	Lighting	466,398	246,258	47%
	Refrigeration	443,540	110,885	75%
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	Other+Power	410,144	410,144	0%
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Heating total	**1,166,454**	**1,063,356**	**9%**
Total (el. Total + PV + heat. Total)	**2,670,597**	**1,707,216**	**36%**

Table 16: Energy consumption distribution for the demonstration site

** Reduction of PV measure applied to total "after" electricity consumption*

Energy savings are dominated by refrigeration, followed by lighting and heat recovery. In total, energy efficiency is improved by 36%.

For all categories of energy use annual consumption profiles exist on a monthly and 15 min basis.

Additionally, the store in Kilkenny runs a backup generator with a power to supply the whole site (site load before: 168 kW, site load after: 136 kW).

For large food stores, benchmark data exist, published in Kolokotroni et al. 2019 with a sample of more than 500 supermarkets in UK. The Kilkenny site has a good energy efficiency performance for electricity but the specific consumption of non-electrical uses is higher than the maximum of the sample. Hence, according to this benchmark, it is expected that in the non-electrical area there should be a large potential for further energy improvements (Table 17).

Energy Use Intensity of large food stores	Total (kWh/sqm*year)	Electricity (kWh/sqm*year)	Non-electrical (kWh/sqm*year)
Average	565	403	162
Minimum	400	260	115
Maximum	740	560	250
Kilkenny Site - Before	614	346	268
Kilkenny Site - After	457	212	245

Table 17: Energy Use Intensity Benchmark

As the Kilkenny site is not implemented as EPC project, no M & V strategy was developed.

5.2 Demand Response Performance Metrics

In Ireland, several grid services can be offered by demand response, differentiated by response time and duration (see Table 18).

Service Name	Acronym	Response	Duration	Appropriate Systems
Fast Frequency Response	**FFR**	2 s (.15 s)	10 s	HVAC/Refr. (54.2 kW), EV (100 kW), Batteries (150 kW)
Primary Operating Reserve	**POR**	5 s	15 s	HVAC/Refr. (54.2 kW), EV (100 kW), Batteries (150 kW)
Secondary Operating Reserve	**SOR**	15 s	90 s	HVAC/Refr. (54.2 kW), EV (100 kW), Batteries (150 kW)
Tertiary Operating Reserve 1	**TOR1**	90 s	5 m	Generator (136 kW), EV (100 kW), Batteries (150 kW)
Tertiary Operating Reserve 2	**TOR2**	5 m	20 m	Generator (136 kW), EV (100 kW), Batteries (150 kW)
Replacement Reserve - Desynchronised	**RRD**	20 m	40 m	Generator (136 kW)
Ramping Margin 1	**RM1**	1 h	1 h	Generator (136 kW)
Capacity	**DSU**	1 h	2 h	Generator (136 kW)

Table 18: Demand response services available for the participation of the case study site

Demand response potential is not sold directly to the grid but via an aggregator. EirGrid, the grid operator in Ireland, pays for the availability of switchable power. The management of the assets is done by the aggregator.

Different assets are used for different services:

- For fast frequency response schemes (duration of 10 s up to 90 s; FFR, POR, SOR) HVAC and refrigeration systems are dedicated (54.2 kW).
- For longer response times (5 min to 2 hours of downtime; TOR1, TOR2, RRD, RM1, DSU) a non-synchronized generator on site can supply electrical demand of the site and the store can be disconnected from the grid (136 kW).
- EV chargers (2 x 50 kW) could participate in FFR, POR, SOR, TOR1 and TOR2.
- Batteries (150 kW) could participate in FFR, POR, SOR, TOR1 and TOR2, too.

The final selection of assets depends on the final project design, i.e. which assets are implemented and can offer the grid services.

M & V was not considered in the case study.

5.3 Comfort Metrics

Comfort issues were not considered in the case study. However, for grid services, it is claimed that client's operation is not affected since each asset on site will be available for a different kind of scheme with different response time.

6 Demo Site: Ballymun and Finglas Leisure Centre, Dublin/IRL

It was originally planned to use Ballymun and Finglas Leisure Centre as a demo site. Due to regulatory restrictions, a full demo could not be implemented. Instead of this, the NOVICE project team decided to carry out a simulated demand response event with the main goal to determine the feasibility of demand response in small to medium sized leisure centres, while assessing the impact on comfort conditions.

The simulation was carried out by installing communications equipment that simulate a Dispatch request from the Transmission System Operator (TSO) by sending a signal to the Building Management System (BMS) to adjust the necessary set points and control parameters to reduce site load. The simulated demand response event involved shutting down all non-essential HVAC equipment for 2 hours between 5pm and 7pm on a weekday evening, the busiest time period for leisure centres. The experiment, showed that approximately 40 kW of flexibility is available at each leisure centre, which is too small to be of interest to most aggregators in Ireland.

Three simulations of a two-hour demand side response event were carried out in three leisure centres in county Dublin, Ireland. Ballymun, Finglas, and Markievicz Leisure Centres trials were carried out in October 2018 to determine the feasibility of the DSR aspect of the NOVICE model in leisure centres of small to medium size.

Noel Lawler Green Energy Solutions (NLGES) provided the sites through their contract with Dublin City Council. Due to current regulatory framework and tariff structures, an actual demand side response event could not take place. The DSR event was simulated by turning down/off non-essential equipment for two hours from 5pm to 7pm.

The occupants of the leisure centres were surveyed in the reception areas of each site before, during, and after the DR simulation. Questions on their overall thermal comfort in the reception area as well as the space they had been in the 20 minutes previously (gym, pool, changing rooms etc.) were asked.

According to this approach, no data for energy consumption or energy efficiency performance are available.

6.1 Demand Response Performance Metrics

The power consumption from the grid was recorded for the first two leisure centres, Ballymun and Finglas. However, the available data for the Finglas centre starts 15 minutes after the demand response event started, so there is no information before the test. The measurement system in the Markievicz leisure centre was less sophisticated and only recorded data every 15 minutes, which was not suitable for the analysis. The electrical flexibility seen in the Ballymun leisure centre is appr. 40 kW, reducing power from 80 to 40 kW. Finglas leisure centre had a slow ramp down of power consumption which shows only a 30-minute interval of its full potential (appr. 40 kW) in the two-hour period, compared to Ballymun. Markievicz leisure centre’s flexibility could not be assessed due to an inconsistency in the recordings.

Figure 11: Ballymum Leisure Centre Power Consumption shows the electricity consumption of the Ballymum leisure centre before, during and after the DR event. The level of flexibility available is shown as the difference between consumption before and during the demand response simulation event.

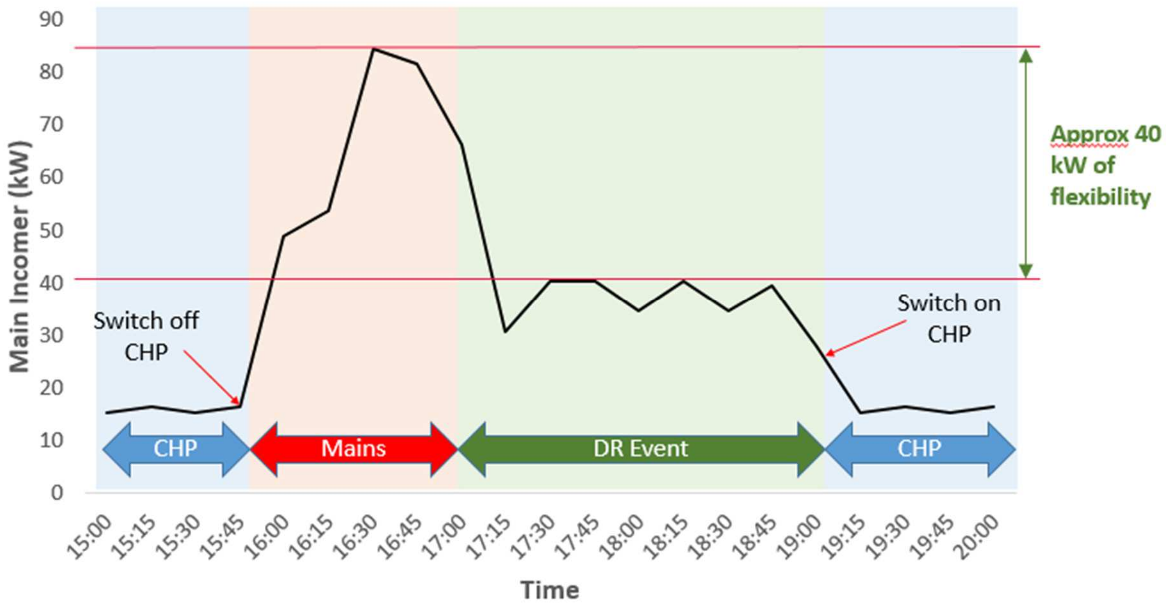

Figure 11: Ballymum Leisure Centre Power Consumption

The CHP was turned off before and during the event so that the flexibility available can be clearly seen in the readings from the recording equipment.

The peak before the DR event begins, shows the normal consumption of the leisure centre. As can be seen on the graph the consumption drops as the DR event begins at 30 kW initially. The flexibility available to the grid is approximately 40 kW at least and it is represented by the difference between the baseline and the test electric consumption. The peaks and troughs during the event show the essential equipment coming on and off to maintain safe operating levels. The significant drop following the end of the DR event shows the CHP being used again for the electricity needs.

Finglas Leisure Centre

For the Finglas leisure centre, the data shows a drop in consumption as the event goes on but this is not an instantanious change in consumption as equipment is turned off/down. It is unclear if the drop is sustainable. The consumption drops throughout the event to a low of appr. 20 kW near the end. The approximate flexibility available, if the drop had occurred more quickly can be assesed to be 40 kW. There is a peak at the end of the event showing that the equipment came back on.

Markievicz Leisure Centre

This leisure centre did not have the same type of BMS as the other two, so measurements were taken using a pulse counter on the main incomer – this proved to be unreliable for accurate conclusions and readings. Consumption of power in Markievicz is assumed to be less than Ballymun or Finglas as this leisure centre is smaller and the level of turn down in this experiment proved unsustainable. Therefore, more power is required during the event with less power used normally leading to less flexibility.

6.2 Comfort Metrics

Indoor air temperature

Table 19: Indoor air temperature levels at the Ballymum Leisure Centre before, during and after the DR event shows the variation in indoor air temperature of three spaces in the Ballymum Leisure Centre at the beginning, during and at the end of the DR event. It can be seen that there is a change of approximately one degree Celsius in all spaces, which is likely not to be perceived by the occupants of the building.

	Start	Middle	End
Pool	23.4	22.3	22.1
Gym	18.6	18.9	18.3
Reception	18.7	19.8	19.3

Table 19: Indoor air temperature levels at the Ballymum Leisure Centre before, during and after the DR event

Relative humidity

Table 20: Relative humidity levels at the Ballymum Leisure Centre before, during and after the DR event presents the relative humidity levels at the Ballymum Leisure Centre before, during and at the end of the DR event. The relative humidity increases from 70 to 99% in the pool area, but the occupants are not likely to observe this difference since most of the occupants will be wet from entering the pool. The relative humidity levels in the gym and reception area have not increased considerably, 16% in the gym area and 1% in the reception area. Since the occupants in the gym area are probably working out and sweating the 16% change in RH will probably not be noticed.

	Start	Middle	End
Pool	70.0	75.7	99.1
Gym	64.1	68.7	74.7
Reception	66.4	64.5	67.1

Table 20: Relative humidity levels at the Ballymum Leisure Centre before, during and after the DR event

CO_2 levels

Carbon dioxide is a normal constituent of the atmosphere with values around 350 ppm in rural areas, 400 ppm in small towns and 450 ppm in city centres (EN, 2007).

Table 21: Indoor air quality categories and their recommended fresh air intake shows the acceptable CO_2 values for indoor air quality by the European standard EN 13779 (EN, 2007). The European standard classifies the indoor air quality in four categories, from IDA 1 – high air quality buildings to IDA4 – low air quality buildings.

Outdoor fresh air is necessary to be introduced in the building in order to dilute the indoor space's contaminants and odours. It has to take into consideration the occupancy rates and activities of occupants and at the same time be in balance with energy conservation requirements. ASHRAE recommends CO_2 levels not exceeding 700 ppm above outdoor levels (ASHRAE, 2007).

Category	Quality	CO_2 above outdoor air (ppm)	Default value (ppm)	Fresh Air Rate (l/s/person)
IDA 1	High	≤ 400	350	>15
IDA 2	Medium	400 - 600	500	10 - 15
IDA 3	Moderate	600 - 1000	800	6 - 10
IDA 4	Low	> 1000	1200	< 6

Table 21: Indoor air quality categories and their recommended fresh air intake

Table 22: Carbon dioxide levels at the Ballymum Leisure centre before, during and after the DR event shows the CO_2 levels at the Ballymum Leisure Centre.

	Start	Middle	End
Pool	745	745	784
Gym	593	942	1073
Reception	530	562	590

Table 22: Carbon dioxide levels at the Ballymum Leisure centre before, during and after the DR event

Both Ballymum and Finglass Leisure Centres remained in a reasonable range of CO_2 levels during the DR event. However, the Markievicz leisure centre trial ended early at 18.30 due to unsafe CO_2 levels. All conditions returned to normal operating levels within 15 minutes of turning equipment back on. This is likely due because of the small size of the leisure centre and the low ceilings.

Thermal comfort

Occupants of the leisure centres were surveyed regarding their thermal comfort levels in the centre. Their perception of the temperature, humidity, and air quality for the reception (where survey took place) and in any other areas of the gym they spent the most time during their visit on the day in question. The questions were carried out by one person on an iPad in all three leisure centres.

Respondents to the survey before the DR event are a control group compared with respondents during the event.

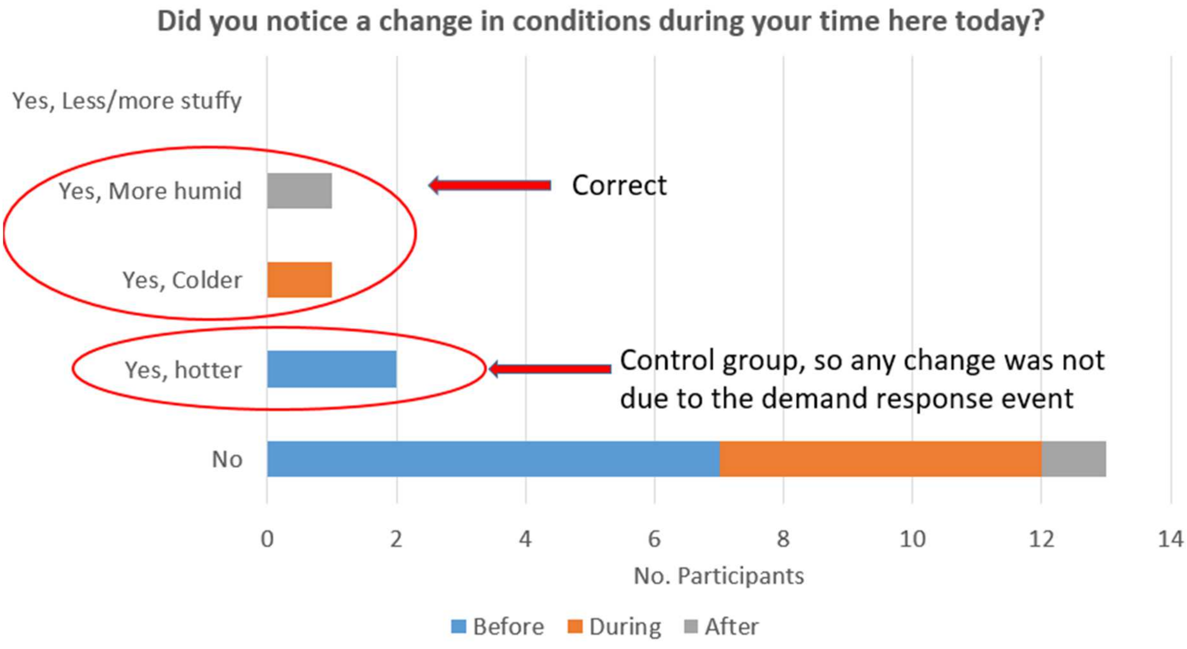

Figure 12: Thermal comfort survey results at Ballymum Leisure Centre

The respondents during and after the DR event had to continue the same trends as before the event in order to conclude no change in comfort levels. Due to the low numbers of participants it is difficult to accurately or certainly say whether there were guaranteed no change in comfort levels. However, the results compiled show little to no dissatisfaction in the leisure centres. A maximum of 24% of participants “noticed” a change in any of the leisure centres, with only 9 to 12% in each trial noticing a change during the DR event that the recorded data supports.

From studies on gender aspects of thermal comfort it can be seen that gender may impact the participant’s response to the survey. Most of the participants were male (61%). This could mean the results are not taking female sensitivity of temperature into account sufficiently for concrete results. In order to have unbiased results, in a future re-run of the trial, more effort should be made to ensure a balanced response from leisure centre users. Age, gender, weight, and thermal history are all factors that have been seen to influence thermal comfort levels (Van Hoof, 2008) (Lan, 2008). This could have an unexpected effect on the results that was not considered.

7 CONCLUSIONS

Performance metrics for the NOVICE dual energy services business model have to be split into energy efficiency performance metrics, demand response performance metrics and comfort metrics. Depending on the particular project, relevant metrics look different. This is especially true for demand response, where metrics have to be adapted to specific market conditions and to the distinction between incentive-based (explicit) demand response and prize-based (implicit) demand response. Furthermore, metrices of the three domains are closely interrelated in some cases. Agreed comfort ranges must not be left in energy efficiency and demand response limiting some opportunities quite strictly.

Performance of energy efficiency improvements and offering demand response require appropriate measurement and verification (M & V) methodologies. It is not widely recognized that M & V methodology for energy efficiency is not the same as M & V for demand response. For the NOVICE dual energy services business model both are necessary but have different requirements.

Even though there is a set of commonly used metrics for all three domains, developed projects will have to look for the very specific framework conditions and requirements. This will result in the need for tailormade performance metrics.

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9 APPENDIX – DATA REQUIRED FROM SITES

Energy efficiency measures data requirements

Data requests	Minimum requirement	Ideal (if available)	Minimum publishing requirements
List of EE measures installed	List of main EE measures installed in last 1-3 years	List of all measures installed in last 3 years	General list of the types of measures installed
Installation dates for each EE measure	Approximate date of install/completion	Actual date of install/completion	Not published
Cost of installation of EE measures	Approximate total cost of the package of measures installed	More detailed breakdown of costs in terms of capital costs (design, equipment purchases, installation, other) and operational costs (maintenance, management, M&V, other) - broken down by measure or by project.	Total cost approximations
Electricity consumption	Monthly electricity consumption data for at least 6 months before installation of first EE measure and 6 months after installation of latest EE measure; or 1 full year before/after EE improvement	15-minute electricity consumption data from 12 months before installation of the first EE measure to 12 months after installation of the most recently installed EE measure	Annual electricity consumption figures and total reductions achieved through the package of EE measures
Gas consumption	Monthly gas consumption data for at least 6 months before installation of first EE measure and 6 months after installation of latest EE measure; or 1 full year before/after EE improvement	60-minute gas consumption data from 12 months before installation of the first EE measure to 12 months after installation of the most recently installed EE measure	Annual gas consumption figures and total reductions achieved through the package of EE measures

Oil/other fuel consumption (if applicable)	Estimate of annual oil/other fuel consumption in kWh/litres/kg of fuel before/after EE improvement	Daily/weekly/monthly measurements of oil or other fuel consumption	Annual oil/other fuel consumption figures and total reductions achieved through the package of EE measures
Electricity price	Site does not provide any data - we assume an average electricity price/kWh based on location and annual consumption and published electricity prices	Actual electricity price/kWh from a sample electricity bill, including any changes over the time period being assessed	Not published
Gas price	Site does not provide any data - we assume an average gas price/kWh based on location and annual consumption and published gas prices	Actual gas price/kWh from a sample gas bill, including any changes over the time period being assessed	Not published
Oil/other fuel price (if applicable)	Site does not provide any data - we assume an average oil/other fuel price/kWh based on location and annual consumption and published fuel prices	Actual oil/other fuel price/kWh from a sample invoice, including any changes over the time period being assessed	Not published
Other site charges (e.g. max capacity, climate change levy, etc.)	Site does not provide any data - we assume these charges based on site location, size and industry standards for these prices	Actual cost of other charges from sample electricity, gas, oil and other fuel bills/invoices	Not published
Funding source for the EE installations	Site does not provide any data - we assume the project was self-funded	Client gives breakdown of funding source i.e. percentage self-funded, grant funded, loan funded etc, plus details of any interest charges on the loan, loan term etc.	Statement of whether a grant or loan was received

Incentives received (e.g. feed in tariffs, renewable heat incentives, capital allowances)	Site does not provide any data - we assume which incentives the project has received based on what was installed, and the incentives available in the country at the time of installation	Breakdown of payments received through each incentive scheme	Total value of incentives received

Demand response data requirements

Data requests	Minimum requirement	Ideal (if available)	Minimum publishing requirements
DR equipment installed	List of equipment installed		General list of equipment installed
Installation date	Approximate date of install/completion	Actual date of install/completion	Not published
Cost of installation DR equipment	Approximate total cost of the package of measures installed	More detailed breakdown of costs in terms of capital costs (design, equipment purchases, installation, other) and operational costs (maintenance, management, M&V, other) - broken down by measure or by project.	Total cost
In which DR programmes is the site participating?	List of DR programmes	List of DR programmes	List of programmes
Revenues from DR	Total annual revenues from all programmes	Annual revenues broken down by DR programme and/or DR event	Total annual revenue

Further details on DR participation		Number of dispatches/year under each programme, date/time of each dispatch, revenue received from each dispatch. Multiple years of data would be beneficial if available particularly if tariffs/availability has changed over time	Average number of dispatches per year

Other information that could be useful

Data requests	Minimum requirement	Ideal (if available)	Minimum publishing requirements
Indication of occupant comfort	Any anecdotal evidence of impact of DR participation or EE measures on thermal comfort/business operation	Any measured data e.g. internal temperature data covering the period being assessed	General impact on thermal comfort/business operation
Site details	Sector, building floor area, approximate location, approximate staff numbers, typical occupied hours, biggest energy consuming areas/equipment	changes in usage of facility before/after EE improvement (production, staff, used floor area, etc.)	Basic site details