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Subject: **IBM EcoGrid Direct-Price Agent Implementation Status**

1 Scope

This document specifices the IBM EcoGrid Direct-Price Agent v3.0 behavior, as an enhancement over the versions 1.0 and 2.1 used in the 2013/14 heating season [1][2].

The new version 3.0 of the price agent aims at increasing the demand-response potential without sacrificing any customer comfort. As introduced in this document, it distinguishes between heat pump installations and direct electric heating installations. Moreover, it redefines the construction of the upper and lower temperature bounds based on the user-set reference temperature and the chosen flexibility level, as well as many timing parameters.

2 Definitions of temperature bands

The user specifies a reference temperature T_r in the GWR UI, see Figure 1 left screenshot (native Danish language version used on Bornholm). Optionally, the user may also specify individual comfort priority and flexibility level, see Figure 1 right screenshot:

Figure 1 GWR UI user settings: The user can decide whether or not to allow automation "Tillad styring", and define individual comfort priorities "Individuelle indstillinger", and modify the reference temperature "Afbryd styring under" (stop control below this temp). Comfort priority settings comprise the day time priority "Prioriter" {Morning, Daytime, Evening} as well as the desired flexibility level "Profil" {Low, Medium, High}. They become active on Save "Gem".

The user-set flexibility levels {Low, Medium, High} translate into a temperature range $T_{flex}(t)$ that determines the allowed temperature *above* the reference temperature T_r. The mapping from flexibility level to temperature range also depends on the comfort priority setting and, thus, can vary over time. In case the user does not select individual settings, cf. left screenshot in Figure 1, a default temperature range is set that is valid for the entire day; it corresponds to the "otherwise" in Table 1 which also provides detailed information about how flexibility and comfort priority settings are translated to allowed temperature ranges, for all comfort priority settings.

Flexibility $T_{flex}(t)$ [°C]	Comfort priority					
	Morning		Daytime		Evening	
	06:00-10:00	otherwise	08:00-18:00	otherwise	17:00-23:00	otherwise
Default	3	3	3	3	3	3
Low	2	2	2	2	2	2
Medium	3	4	3	4	3	4
High	4	6	4	6	4	6

Table 1 Flexible temperature range $T_{flex}(t)$ [°C] for different levels of flexibility and comfort priorities. These values apply to both heat pump and electric heating installations. In case the user does not specify individual settings, the default values "otherwise" are applied.

In addition to the user settings, the temperature set point for the heating devices' internal thermostat control T_{th} must be set such that $T_{th}>=T_r+\max\{T_{flex}(t)\}$. This lower bound on T_{th} is required to guarantee

that the heating devices will turn on whenever they are enabled by the IBM price agent. However, T_{th} should be chosen such that this temperature is acceptable in the worst case, see Section 5 for more details.

3 Heat Pump Model and Constraints

The version of the direct-price agent described in this document uses a very simple heat pump model. It is assumed that the heat pump consumes a constant amount of power P_{ON} when in operation, and a constant amount of power P_{OFF} when idle.
The numeric power level values can be identified for every house individually. Table 2 provides a set of typical values.

Heat Pump Operation Stat	*Constant Power Consumption*
ON	4000W
OFF	130W

Table 2 Example of heat pump power levels.

The heat pump runtime constraints used in the new price agent version 3.0 are provided in Table 2 for different flexibility levels. In contrast to previous versions of the direct-price agent, the maximum total off-time is now specified for 24 hours.

User-set Flexibility Level	*Min. Off-time*	*Max. Off-time*	*Min. On-time*	*Max. total Off-time per 24h*
Low	30min	30min	120min	180min
Medium	30min	60min	90min	360min
High	30min	90min	60min	720min

Table 3 Heat pump (HP) operational constraints for different user settings.

4 Direct Electric Heating Model and Constraints

The model used for direct electric heating is similar to the heat pump model introduced above. It also assumes constant power consumption if the device is ON. If it is OFF, no power is consumed at all.

Electric Heating Operation State	*Constant Power Consumption*
ON	4000W
OFF	0W

Table 4 Example of electric heating power levels.

The electric heating runtime constraints used in the new price agent version 3.0 are provided in Table 5 for different flexibility levels. The dynamics of an electric heater are assumed to be very fast. Thus, only short minimum ON/OFF times are considered.

User-set Flexibility Level	*Min. Off-time*	*Max. Off-time*	*Min. On-time*	*Max. total Off-time per 24h*
Low	5min	10min	5min	180min
Medium	5min	15min	5min	360min
High	5min	20min	5min	720min

Table 5 Direct electrical heating (EH) operational constraints for different user settings.

5 Behavior of Price Agent

This section describes the behavior of the new price agent v3.0. There are 3 different behavioral modes depending on the current temperature T(t), the thermostat set point T_{th}, and the user settings.

1. The temperature is **below** the reference temperature ($T(t)<T_r$):
   In this case, the heating devices are constantly enabled.

2. The temperature is **within** the flexible temperature range ($T_r<=T(t)<=T_r+T_{flex}(t)$): In this temperature range, the heating devices are enabled or disabled with the goal of minimizing energy costs based on the EcoGrid real-time prices. All the operational constraints as defined in Tables 3 and 5 are considered.

3. The temperature is **above** the allowed temperature range ($T(t)> T_r+T_{flex}(t)$):
   In this case, the automation switches to the flexibility level `High' that allows for maximal OFF-times to correct over temperatures, but still under the operational constraints of High as defined in Tables 3 and 5.

Disclaimer: Note that it is possible for the temperature to go below T_r or exceed $T_r+T_{flex}(t)$. Even when the agent will switch to behavior (3) in above list and run the automation with a flexibility level `High', decreasing of the temperature may not always succeed. The actual house indoor temperature depends on many external factors. Examples include: open doors and windows, the current weather situation, solar irradiation through windows, the thermal characteristics of the house, and also on potentially other active but uncontrolled heating devices.

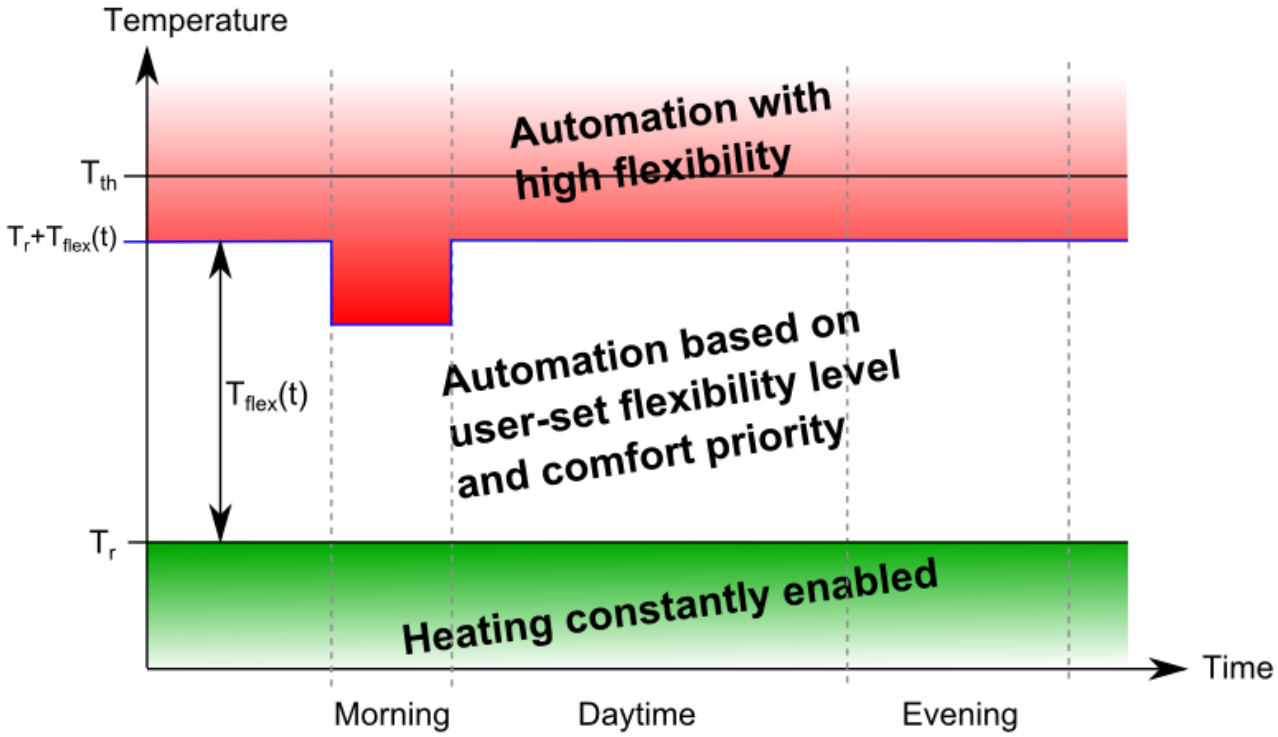

Figure 2 Definition of different temperature bands. The minimum required temperature T_r is set by the user in the GUI. If the actual temperature drops below this value, the heating devices are enabled constantly. The upper temperature limit is given by adding the flexible temperature range $T_{flex}(t)$ to T_r. If the temperature exceeds this value, the heating devices are controlled with high flexibility with the aim of bringing the temperature below T_{th} again. A large thermostat set point temperature T_{th}, where $T_{th}>=T_r+\max\{T_{flex}(t)\}$, is required for the devices to start heating whenever they are enabled by the IBM price-agent.

6 Energy-Procurement Cost Minimization

Given a price forecast for a fixed planning horizon, the IBM direct-price agent version 3.0 computes a heating device enablement schedule that (i) minimizes the total energy-procurement cost accumulated over the planning horizon based on the EcoGrid real-time price and that (ii) simultaneously satisfies all operational constraints as specified in Tables 3 and 5 depending on the device type.

7 Security Features

In addition to the operational constraints discussed in Sections 3 and 4, the following security features are implemented to guarantee pilot participant freedom and best-possible efforts to establish an indoor air temperature higher or equal to the user-set minimum comfort temperature at all times.

As soon as at least one of the following conditions is true, *any* planned minimum procurement-cost enablement schedule will be pre-empted and the heat pump is unconditionally enabled to operate according to its native parameters.

i. The indoor air temperature as measured by the GreenWave temperature sensor is below the user-set minimum temperature T_r.
ii. The latest indoor air temperature values received from the GreenWave temperature sensor are older than 4 hours ago.
iii. The communication between server and GreenWave gateway in house is lost for more than 30 minutes (in this case the automatic scene will be executed).
iv. Oestkraft or the participant operationally bail out the household from automation by unchecking the optimize flag in the GreenWave user interface.
v. The IBM-agent administrative automation state for the household is set to disabled (example as done over Christmas Holiday Season 2013/14).

References

[1] Mueller, F., Sundstroem, O., Gantenbein, D. (2013). *IBM EcoGrid Direct-Price Agent Implementation Status v.1.0.* IBM Research Zurich.

[2] Mueller, F., Sundstroem, O., Gantenbein, D. (2014). *IBM EcoGrid Direct-Price Agent Implementation Status v2.1.* IBM Research Zurich.