Deployment and User Interface Guide

TIBUCON is financially supported by the European Commission under the 7FP.

Self Powered Wireless Sensor Network for HVAC System Energy Improvement Towards Integral Building Connectivity

TIBUCON SYSTEM COMPONENTS

The TIBUCON system is composed of multiple elements, comprising both software and hardware. This section describes all the components and the interactions between them.

Multi-Magnitude Sensor

The TIBUCON sensor platform is designed for monitoring of climatic changes in closed areas. The gathered information includes temperature, humidity, light intensity and presence (optionally).

The sensor is self-powered by means of an indoor solar panel, extending its autonomous operation practically forever. However a backup battery can be attached to the device to guarantee quality of servive (QoS) under extended poor light conditions or scenarios were ambient light is not available at all.

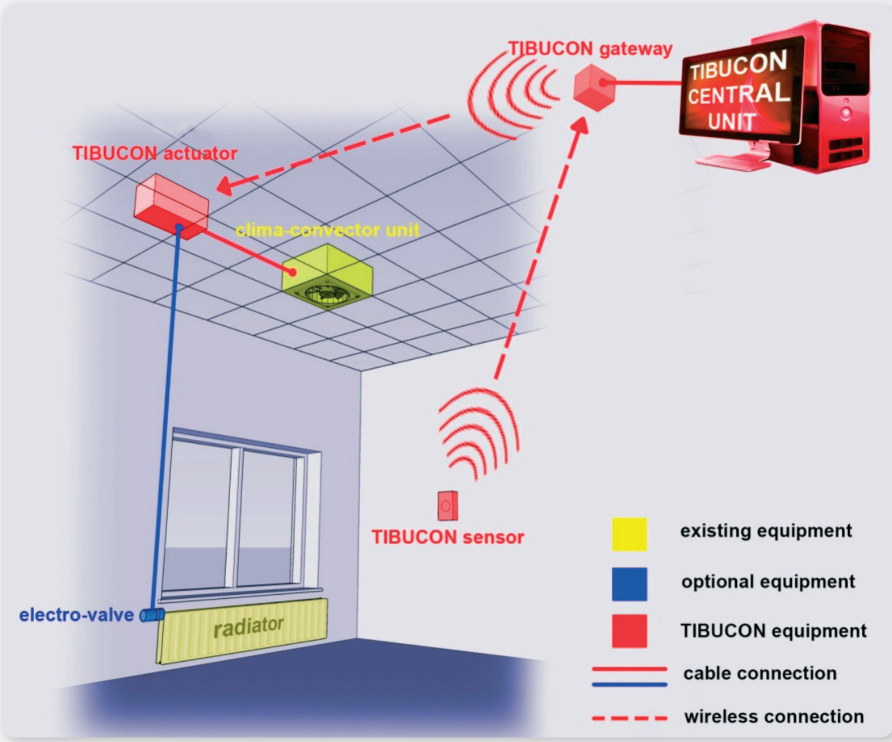

Figure 1:TIBUCON system scheme in office building.

The TIBUCON sensor communicates wirelessly with other system components and can be placed to increase the resolution of a monitored area or to define independent areas for HVAC control.

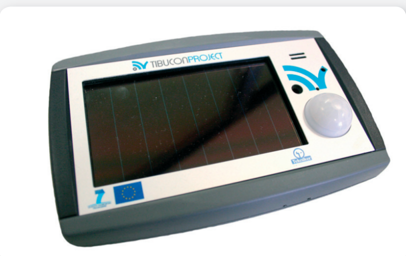

Figure 2:TIBUCON sensor.

Figure 3:TIBUCON Bridge connected to radiator valve actuator.

TIBUCON Bridge

The TIBUCON Bridge has 2 digital inputs, 2 digital outputs, 1 analog input and 1 analog output. Both the digital and analog channels have been designed as generic purpose I/O and they can be used to interface to external sensors/actuators.

The TIBUCON Bridge communicates wirelessly with the other system components and can be easily installed to control and monitor a wide range of commercial actuators. Power sources of

12-24 V DC and 220 V AC are supported. At the TIBUCON test deployment one Bridge was used to control each heater and clima-convector.

Figure 4: Electro-valve to control heaters.

Figure 5: TIBUCON Gateway.

Electro-Valve

The commercial electro-valves are used to replace the original thermostatic valves on heaters. These electro-valves are controlled and powered by TIBUCON Bridges.

TIBUCON Gateway

The TIBUCON Gateway acts as the manager of the wireless sensor network (WSN) and also the interface between the wireless and external networks. Typically the gateway connects to a remote machine (hosting the TIBUCON Central Unit) and acts as a broker for the data coming from the WSN and commands issued by the Central Unit. At the TIBUCON test deployment the gateway was directly connected to a laptop by means of a local TCP/IP connection.

TIBUCON Central Unit

The TIBUCON Central Unit comprises the management and control software for the TIBUCON project. The main tasks of the Central Unit are data management and control of the performance of the HVAC system, achieved by continuous measurement and actioning feedback processes in real time. At the TIBUCON test deployment the Central Unit was hosted on a laptop running the Windows 7 operating system.

Figure 6: TIBUCON Central Unit.

DEPLOYMENT

In order that the sensors measure the comfort-dependent internal temperature, they should not be mounted on exterior walls, nor near heat generating devices (e.g. printers). Moreover sensor devices powered by a solar panel optimised for artificial light sources cannot be mounted in a dark place. The selection of locations for the TIBUCON sensor nodes should depend on the following technical considerations:

- The local illumination, so that the node can harvest enough energy.
- The local thermal climate, so that the sensed temperature (and possible other measured variables) are representative for the controlled zone.
- A good view towards the activity of the occupants, so that their presence can be detected with a high accuracy.
- The distance to the rest of the network, so that stable communication is ensured.

During the deployment the following further criteria appeared to be at least as important as the technical considerations regarding the sensor location:

- The visibility and looks of the sensor in relation to the rest of the interior design.
- The possibility of hindering the circulation of occupants or risk of sensor damage.

Figure 7: Mounted TIBUCON sensor – below existing HVAC thermostat.

Figure 8: Mounted TIBUCON actuator bridge.

The picture below shows the devices installed in one of the rooms.

Figure 9: Location of TIBUCON equipment in office room.

Communication Issues

Deploying extra sensors also benefits the communication network since the distances between the nodes will be smaller. Moreover, if more sensors are deployed there is less chance of communication errors if a few sensors go into hibernation mode due to a (temporary) lack of energy. Special care should be taken if the communication path crosses metal constructions (e.g.an elevator shaft) and/or reinforced concrete constructions. In these cases extra nodes on either side of the construction can help to bridge the obstruction.

Illumination and Energy Harvesting

Since the sensor nodes are powered by energy harvested by the PV-panel, the illumination level of the location should be high enough. The demonstrations show that this is easier in an office environment than in a residential context. One key difference between the two deployment locations is that the commercial environment is designed to give illumination levels of at least 500 lux, whilst the residential properties are typically not as brightly illuminated by artificial lighting. In dwellings it is therefore crucial that the sensor node is sited in a position where it will receive enough solar energy, and on a regular basis. The sensor nodes should thus be installed with the PV-panel (front) turned towards the windows. However, in residential areas there is the risk of inhabitants moving the sensor node around, obstructing it with furniture, or leaving the house with closed shutters or blinds. Extended periods of obscured illumination should be avoided at all times if the sensor is to be kept alive.Energy problems can also arise in an office environment if the PIR sensors in the nodes are activated. The presence detection consumes a lot of energy and PIR equipped nodes are thus best located in the highest illuminated areas of the zone. The ability of the nodes to harvest from both artificial and natural light allows the nodes to continue to harvest energy and operate during periods when the artificial lighting is not active, such as weekends.

Presence Detection

To measure the occupancy of the room, the PIR sensors should be faced towards, and not be too far from, the possible occupants. This requirement can be contradictory to the first guideline to face the node towards the highest illumination for energy harvesting efficiency and the resulting compromise location can thus lower the autonomy of the device.

Thermal Comfort

Since the temperature measurement has either a direct (closed control loop) or indirect (open loop control) effect on the heating system, it is important that the sensors correctly measure the thermal comfort of the occupants in a zone and that temperature changes in the zone are quickly noticed. Regarding the thermal comfort, the sensors should best be located close to the occupants, but without hindering the occupants in their movements nor above specific sources of heat (computer, TV, printer, desk lamps, …). In practice this means that sensors are often wall mounted. Care should be taken that the climate on this wall is representative for the rest of the heating zone. Therefore it is best not to choose an outside wall (which can be colder) and the wall around the sensor should be free of other items so that internal air movements can pass freely around the sensor. The sharpest increases in indoor temperature are caused by heat gains (solar gains, internal gains) and/or the heat emitted by the heating system itself. If these rising temperatures are measured too slowly overheating can occur, as measured in the office demonstrator case. Placing the sensors just under the window sill, facing the occupants and in between the

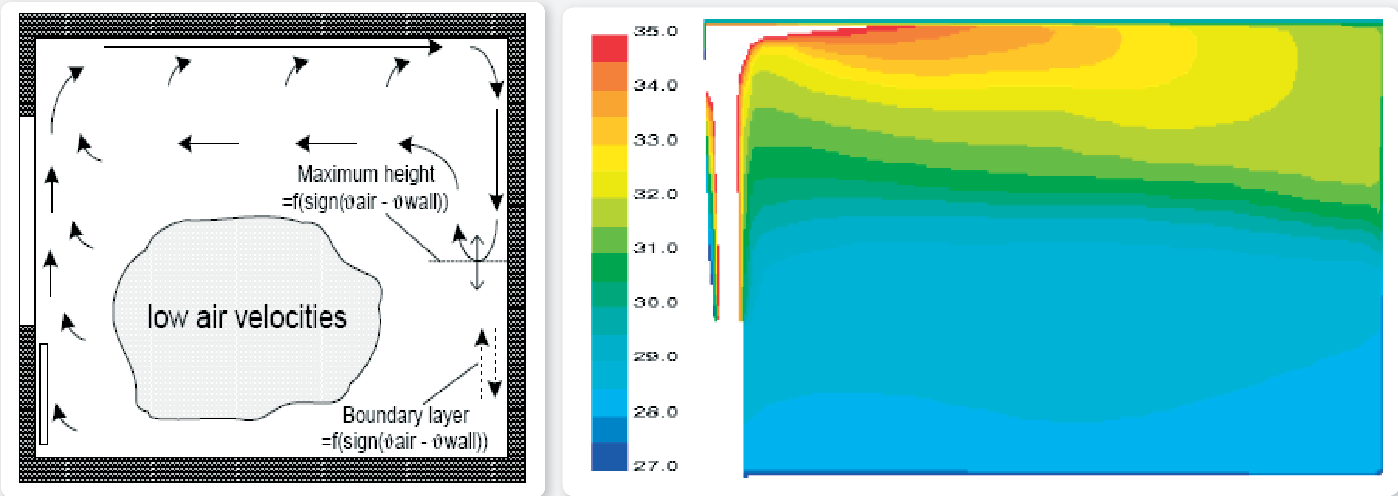

Figure 10: Heat flow[1] and temperature distribution[2] in a room heated by a radiator under a window.

radiators, seemed practical, non-intrusive and a good location for the PIR readings, but gave comfort issues as temperature fluctuations were measured too slowly. The opening of windows will cause a sharp decline in temperature, but this does not have to be compensated for since the initial temperature drop is wanted, or at least accepted, by the person opening the window. Moreover, increasing the heat output under an open window will cause a lot of extra heat losses. Since the heat output from the heat emitters and the free gains cause a heat plume rising to the ceiling and causing stratification with hot air coming down from the ceiling, the best location to measure this temperature increase is:

- Across the room from the heat emitters.
- Preferably on an internal wall without cupboards, shelves or other things attached to the wall above or under the sensor.
- High enough, at least at 1.4 m height from the floor.

On the other hand, if the zone temperature is sensitive towards solar energy and heats up easily, the sensor can also be put in the direct sunlight; in this way it will be possible to quickly shut down the heat emitters. This can be safely done in the case of a smaller office room. However, if a heating zone is rather large, such as an open office space or a whole apartment with different rooms, care should be taken that other areas will not become too cold at the same time. Therefore, the orientationof the different rooms or areas in one control zone should be studied beforehand. Figure 11 and Figure 12 show the solar irradiance during the morning in a South-East oriented apartment of the Lorea residential demonstrator. The living room is the central, irregular formed zone and is facing south. The bedrooms are taken together as one night zone at the left side of the figure, situated on the south-eastern corner of the building.

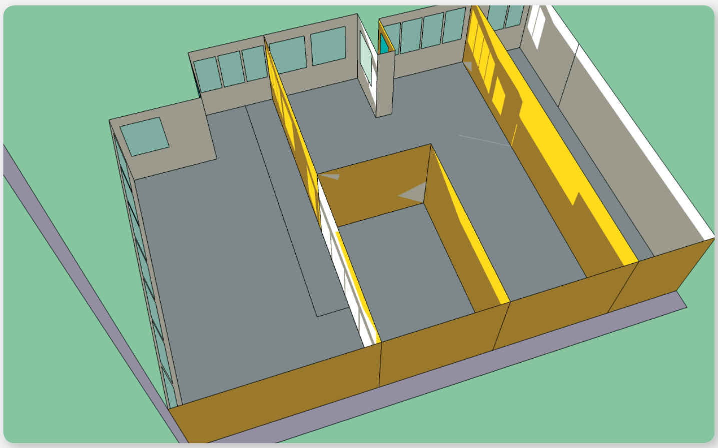

Figure 11: Solar irradiance of inner walls of an South-East oriented apartment during the morning.

1) P. Riederer, Thermal modelling adapted to the test of HVAC control systems, Ph.D.
2) J.A. Myhren & S. Holmberg, Flow patterns and thermal comfort in a room with panel, floor and wall heating, Energy and buildings

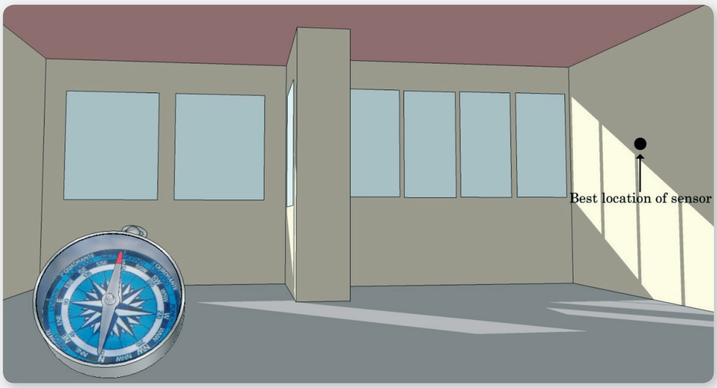

Figure 12: Solar irradiance in the living room during the morning

Figure 12 and Figure 13 show that during the morning both in the living room and the bedroom zone solar energy is entering and the western walls are irradiated. When it is getting later, the sun will turn towards the west and the mostly eastern oriented bedrooms will be shaded by the rest of the building (see Figure 15), while the southern oriented living room is still receiving solar energy and its eastern inner wall is still irradiated (see Figure 14).

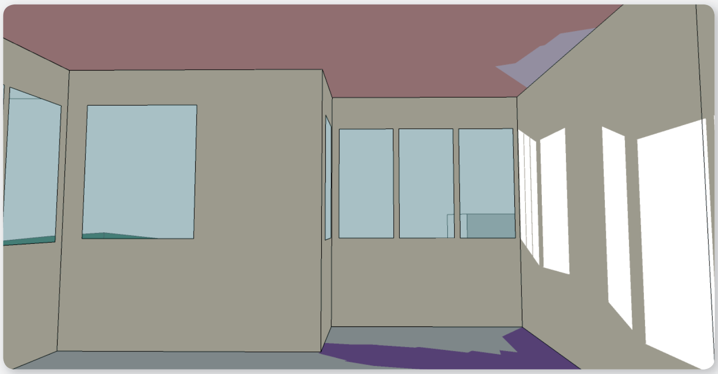

Figure 13: Solar irradiance in the bedrooms during the morning

It is clear that in this case (for these orientations) the sensor should be placed on the western living wall. If the sensor were to be irradiated directly or be influenced by the wall heating up underneath it and measure temperatures that are too high, this would happen during the morning while the bedroom zone in the apartment is receiving direct irradiation as well. Switching off the heating would be no problem at that moment. If the sensor were to be placed on the eastern wall, the misreading and heating abatement would happen during the evening while the bedrooms are already cooling down. Under-heating can occur at this time. An easier, safer, but more expensive option, is to add more sensors in a large climatised zone so that temperature differences over the zone are measured directly. With the TIBUCON control system it is possible to control heat emitters individually so that local under-heating can be tackled, without overheating other areas. If individual control is not possible due to practical reasons (e.g. heat distribution), all measured temperatures in the heating zone should be kept within the comfort temperature bands, as shown in Figure 16. Controlling the emitters based on the average temperature can in some cases still lead to local over- or under-heating.

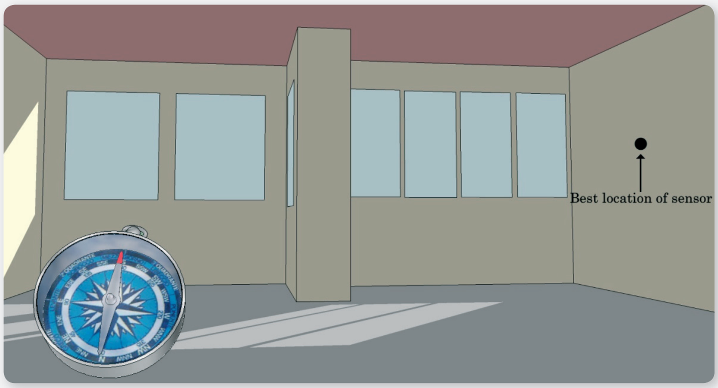

Figure 14: Solar irradiance in the living room in the afternoon

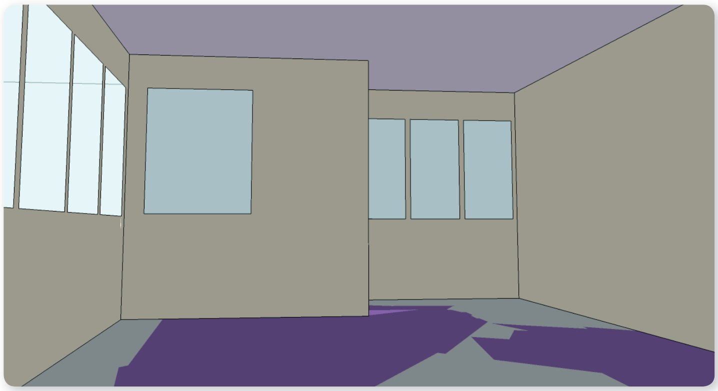

Figure 15: Solar irradiance in south-east oriented bedroom zone during the afternoon

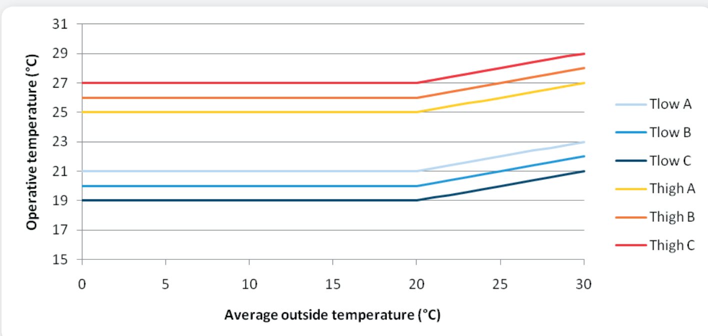

Figure 16: Boundaries for the operative indoor temperature in relation to comfort level (A/B/C) and daily averaged outside temperature

Examples

Figure 17 shows possible locations for the TIBUCON sensor nodes in a larger open office space. To measure a representative temperature the sensor could be placed in the middle of the room close to the occupants, such as at no.7 in the figure, but this is often not practical and the PIR sensor can only cover a part of the room. The node(s) should not be put on an external wall either, since temperature readings are often not representative for the room and indoor temperature fluctuations can be noticed too late, see section 2.4. Placing the node on the back wall, can also be disadvantageous, since the light levels for the energy harvesting can be lower. For location no. 5 there is also the risk that an opened door can cause incorrect temperature and/or occupancy readings.

It is safest to put the TIBUCON nodes on a side wall, high enough up the wall, so that the temperature fluctuations caused by the heat emitter can be felt soon enough, the PIR sensor can have a long reach, and the light levels are high enough as well. The choice of the side wall can depend on the influence of the solar energy coming in through the windows; if the room heats up fast, the node should be put so that direct solar light is felt in the morning and the heating can be shut down faster. On the other hand, if the average room temperature is hardly affected by the solar energy, direct sunlight on the sensor should be avoided. The exact location can also depend on cupboards or other obstacles attached to the wall. Above and below the sensor the wall should be free of obstructions, so that the air moving down from the ceiling or coming up from the floor can flow easily around and through the sensor case. And lastly, the sensor should not be put above a printer or a fax machine, such as location no. 3, since localised heat sources such as this can influence the temperature readings as well.

So that leaves locations no. 4 and 6 as the best options in Figure 17. Actually a combination of both would be even better since the quality of the occupancy detection will increase, certainly in a case of a long and narrow zone. Also the influence of heterogeneous heat sources, such as solar and internal gains, can be measured better with multiple sensors, so that both sides of the open space can be kept in the best possible comfort. With the comfort boundaries of Figure 16 in mind, it should always be possible to maintain a comfortable temperature for all the occupants in the open plan office.

Figure 17 Example of possible sensor locations in a larger open office space; locations no. 4 and 6 are preferable

SOFTWARE

The Data Collector is the central component of the control system. It receives and stores the data from the WSN and sends commands towards it. In summary it acts as the interface to the WSN.

The Network Manager Application (NMA) is used for debugging and management purposes. It allows for real time monitoring of the WSN system and is able to change specific parameters of the network. The NMA is not necessary for normal system functionality and it is only intended for the supervision of the WSN system.

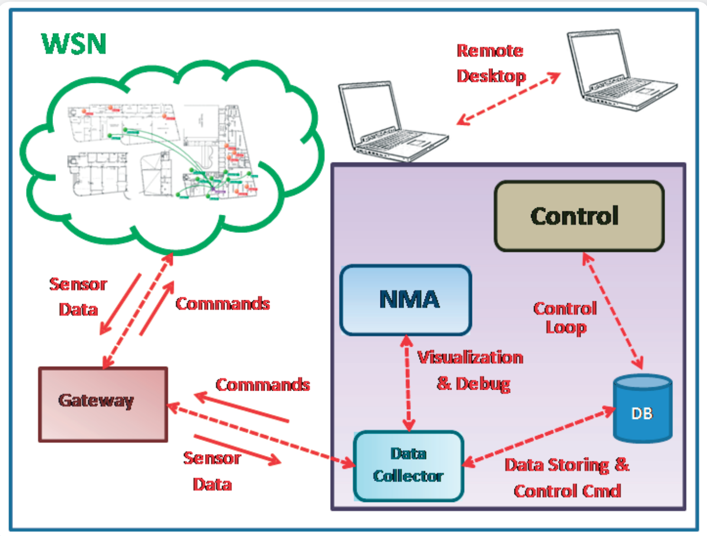

Figure 18: TIBUCON architecture at Computer.

The set-point control (SPC) application, implements a parameter based set-point control for the actuators, taking into account office hours and measured occupancy. The set point control modifies the zone set points between four possible states, based on detected occupancy (occupancy detected/no occupancy detected) and office time schedule (on/off), with customisable temperature profiles for the set points:If occupancy is detected during office hours, the most narrow temperature band is maintained, between the heating and cooling set point for that zone.

- If during office hours, no occupancy is detected, a small temperature setback, named "Unoccupied (office hours) setback" is introduced to this temperature band.
- Outside office hours, when no occupants are present, the heating and cooling set points are reset to a wider band, based on a "night/weekend setback".
- If outside of the office hours, a person enters and occupies the zone, an improved comfort level would be desirable and the comfort goals are increased equal to the "Occupied weekend setback".

A visual representation of this control algorithm active over a period of 3 days is presented in Figure 19. The top section of the image shows the effect on the cooling set-point (blue line) and the heating set-point (red graph). Inputs for the program are available from the HVAC hours and office hours parameters (middle section of image) and occupancy (bottom section of image).

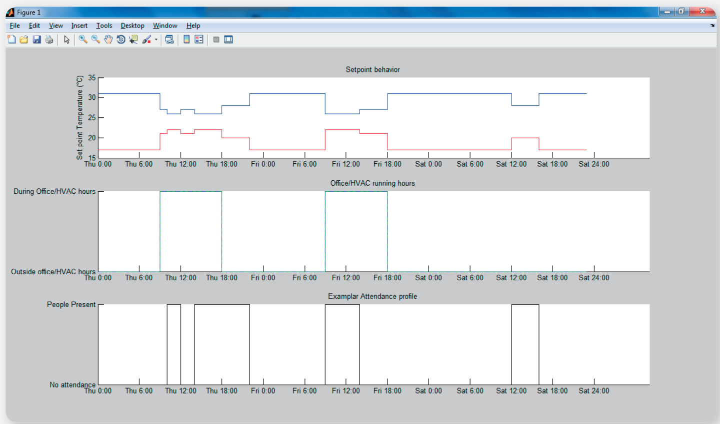

Figure 19 Fictitious example of set point program (Thursday to Saturday)

To adjust the parameters suitable for your application, two graphical user interfaces have been developed, a Simplified Set-point Editor (SSE) and a parameter editor (PE).

Tool: Simplified Set-point Editor (SSE)

The simplified set-point editor is a Graphical user interface (GUI) for the building manager or company responsible, to adjust zone set-points during occupancy, based on user preferences. This interface (as shown in Figure 20) provides only a few options, such as changing zone set-point and individual actuator set-point adjustments (for subzonal temperature control). Since this interface is usable by larger group of less experienced users, the functionality is foreseen that a custom dictionary file can be provided, so that the interface is displayed in any language required (two custom languages can be used). It is possible to switch from one language to another (in the example these are English and Dutch).

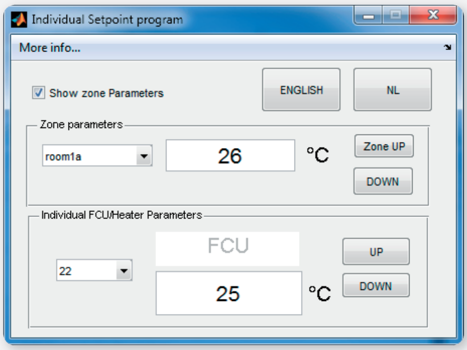

Figure 20 Simplified Set point control interface.

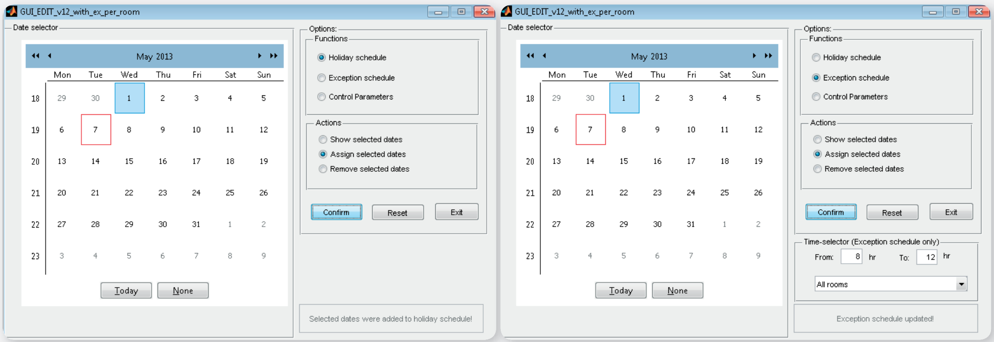

Figure 21 Interface for exception schedule and holiday schedule. These calendars allow the building manager to enter special dates where the typical week schedule should be overridden to night/weekend regime (holiday schedule) or to office hours regime (exception schedule).

Tool: Parameter Editor (PE)

The parameter editor application is another GUI for the building manager, to adjust set-point parameters and schedules used by the set point control (SPC) software.

This interface (as shown in Figure 21 and Figure 22) provides three tab pages, where respectively: holiday schedules; exception schedules; and detailed parameters can be adjusted per zone. This interface is slightly more complicated than the SSE software, but allows for higher flexibility and energy savings, since it allows the controller to be tuned specifically towards the function of each zone. For each parameter, some explanation and a default value is proposed on mouse-over.

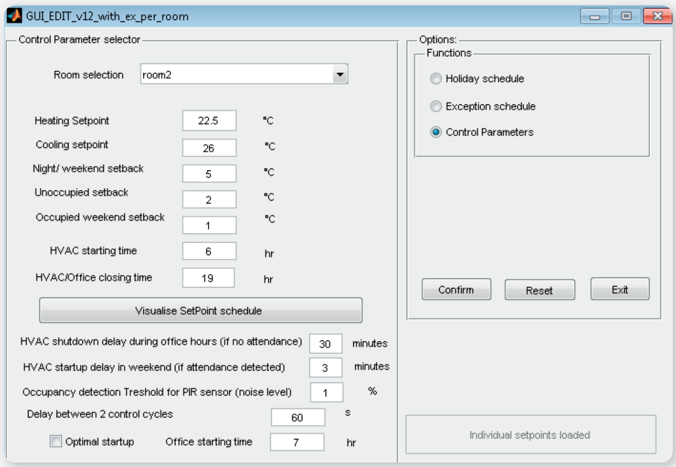

Figure 22: Interface for the building manager to adjust configuration parameters for the set point control. Note that all names and properties of the zones are extracted from the database, which makes the TIBUCON system very flexible to expand or adjust to user preferences and office schedules, and to other deployments.

PROJECT INFORMATION

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PROJECT DETAILS

- Project Acronym: **TIBUCON**
- Project Reference: **260034**
- Start Date: **2010-09-01**
- Duration: **36 months**
- Project Cost: **2.46 million euro**
- Contract Type: **Collaborative project** (generic)
- End Date: **2013-08-31**
- Project Status: **Execution**
- Project Funding: **1.59 million euro**
- Website: **www.tibucon.eu**
- Website: **www.tibucon.info**

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