# AGILE

***rApidly-deployable, self-tuninG, self-reconfIgurabLE nearly-optimal control design for large-scale nonlinear systems***

***257806, FP7-ICT-2009-3.5***

# Technical Note WP6_TN_EP:

# Draft Evaluation Plan

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## Technical Note IR_EP: Short Description

The purpose of this Technical Note is to provide an analytical plan of the evaluation of the AGILE system to the two Test Cases.

**Keywords:** large-scale control systems; traffic control; energy building control; field evaluation

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# Executive Summary

The purpose of this Technical Note is to provide a draft plan of the evaluation of the AGILE system to the two Test Cases. After the on-line testing of the system on the two large-scale control problems – the urban traffic control and the buildings' energy control – the phase of the real implementation of the system is going to take part. This document describes the evaluation procedure that is going to be followed in each Test Case separately, according to its special formation and characteristics. The results of the evaluation are going to demonstrate the impact of the developed system in terms of technical, operational and economic aspects.

# 1 Introduction

The purpose of this Technical Note is to provide a draft plan of the evaluation of the AGILE system to the two Test Cases. After the on-line testing of the system on the two large-scale control problems – the urban traffic control and the buildings' energy control – the phase of the real implementation of the system is going to take part. This document describes the evaluation procedure that is going to be followed in each Test Case separately, according to its special formation and characteristics.

The AGILE system will be applied, evaluated and compared against well-established and intensively fine-tuned Large-Scale Control Systems (LSCSs) in two different real-life nonlinear large-scale systems (Test Cases) possessing a variety of design and performance characteristics, extremely complex nonlinear dynamics, highly stochastic effects, uncertainties and modeling errors, as well as reconfiguration and modular design requirements The results of the evaluation are going to demonstrate the impact of the developed system in terms of technical, operational and economic aspects.

## 2 Test Case 1: Urban Traffic Control

The first test case is related to the design, testing and evaluation of AGILE system for controlling – in real-time – the traffic light signal settings of the urban traffic network of the city of Chania, Greece. The particular large-scale system comprises 24 junctions, around 100 control inputs (traffic light signal settings), around 200 sensor measurements (measuring traffic flow and occupancy at the network's links), and it is subject to highly nonlinear and discontinuous dynamics (mostly due to the on-off behavior of the traffic lights) as well as stochastic traffic demand patterns. It is worth noticing that the particular traffic network becomes extremely congested during business hours and especially during the summer when the population of the city is doubled due to tourists.

The urban road traffic network of Chania (Figure 1) contains virtually all possible varieties of complex junction staging. The kernel of the signal-controlled network has a total length of approximately 8 km. Several additional signal-controlled junctions are encountered in off-centre parts of the city but are operated as isolated junctions without connection to the central control room. The majority of the streets in the kernel network consist of only one lane, which means that unexpected events (incidents, deliveries etc.) may block the street and deteriorate the traffic conditions, even if their duration is only a few minutes.

Apart from dealing with the nonlinear, discontinuous and stochastic nature of the particular application, the AGILE LSCS design will have to face a number of problems that make the particular application extremely challenging: (a) any control design for this system has to be rapidly fault-recoverable as a significant portion of the sensors are erroneously measure "congested traffic" because there are cars illegally parked above them; (b) moreover, control designs for these systems have to be able to rapidly and efficiently be reconfigured as quite frequently part of the traffic network is not "functioning" (mostly due to unforeseen events/incidents taking place at the city centre that lead to closing the streets of the city centre and having the drivers taking alternative to the usual routes); (c) finally, due to significant changes in traffic demand patterns (e.g. summer vs. the rest of the seasons), efficient control designs for this particular system will have to be self-tunable so that they take care of the significant seasonal traffic demand variations.

**Figure 1:** AGILE Test Case 1: Chania Urban Traffic Network. Location: Chania, Greece

## 2.1 Resident control strategies

All the controlled junctions are monitored by the SIEMENS MIGRA CENTRAL. The MIGRA system belongs to a new generation from the world of Siemens Central Systems, and has been provided by Siemens AG through Siemens Greece. In general the SIEMENS MIGRA CENTRAL system provides:

- Complete surveillance of the junctions (malfunctions, damages, outage etc.)
- Complete co-ordination of the junctions
- Changes of the signal plans based on the TASS strategy.

The system is also able to supervise all the junctions in order to detect their operation or damage and also the kind of damage that has happened. In case of any incident the system represents it using the following indicators:

- Green light: Junction works properly
- Red light : Problem in the power supply
- White Light: Problem in the communication of the junction with the MIGRA system, mostly because of the modem.

The system operator can not only detect which program (traffic strategy) operates at any time (chosen automatically by MIGRA) but also he could change it manually or he could set out of operation a specific controller. Furthermore via the MIGRA system can observe at any time the occupation, speed and other related data in the main traffic arteries of the city.

As already mentioned the MIGRA system applies the TASS strategy in the junctions and keeps them under surveillance. TASS is a “quasi” real-time UTC strategy which selects, every 15 min, one out of six pre-defined (60, 70, 80, 90 IN, 90 OUT, 100) fixed-time network-wide signal plans (each with different cycle, splits, offsets), depending on the current traffic conditions in the network (that are reflected in the real-time measurements of 17 “strategic” detectors), and transfers the selected plan to the junction controllers for application. The junction controllers may modify (within certain limits) the received signal settings by application of a simple traffic-actuation logic based on local traffic measurements (micro-regulation). The strategy includes a very high number of parameters and settings that were extensively fine-tuned to virtual perfection for more than five years.

The TASS requirement for intensive and tedious fine-tuning is a disadvantage due to the medium-term changes in the demand patterns (aging of the pre-fixed signal plans), the seasonal demand changes as well as in case of alterations of the network layout (mainly due to a new master plan). Thus the city authorities decided in the year 2002 to also deploy the real-time UTC strategy TUC (under the European project SMART NETS). TUC consists of four distinct interconnected control modules that allow for real-time control of: (a) green times (split); (b) cycle time; (c) offsets; and (d) for the provision of public transport priority (not implemented in the traffic network of Chania). These four control modules are complemented by a fifth data processing module. All control modules are based on feedback concepts of various types, which lead to TUC’s computational simplicity as compared to model-based optimization approaches, without actually sacrificing efficiency. For its operation, TUC calls for one message exchange per cycle between each local junction controller and the traffic control room (located in Chania City Hall).

## 2.2 AGILE system evaluation

The evaluation phase of AGILE system will cover a period of up to 9 months so as to enable a sensible evaluation and provide the necessary time margin in case of unexpected implementation delays. The two following subsections describe two different sets of experiments that will be conducted for the comparison of AGILE with the resident operating control systems.

### *2.2.1 Weekly alternation of the two systems*

A weekly alternation of the two systems is going to take place (i.e. one week the Test Case will operate with the resident control system being active and next week it will operate with AGILE system being active and so forth). The weekly alternation for a long period of time between the two systems will allow the evaluation process to gather sufficient number of data for both systems and for comparative fault/incident/weather/demand conditions, something that will allow a comprehensive and fair evaluation of the AGILE overall system (in comparison with the resident systems).

### *2.2.2 Competition under artificially-imposed incidents*

The second set of experiments involves testing the two competing LSCSs (AGILE and the respective resident system) under artificially-imposed abnormal operating conditions. More precisely – and based on an Artificial Incident Scenario (AIS) plan to be defined during the implementation phase – different sets of 2-day experiments will be conducted. At each of these 2-day experiments a particular combination of system components (sensors, interfaces, actuators and controllers) is intentionally shut down or disconnected from the central control system, so that the overall Test Case system faces significant performance problems.

For instance, in one of these experiments some of the local junction controllers in the city centre will be disconnected during peak hours, operating with fixed-time control at these hours. For each day of these 2-day experiments, one of the two competing systems will be implemented (daily alternation); special care will be given at the preparation of the AIS plan so that both days of these 2-day experiments preserve similar weather, traffic/occupants demand characteristics (so as to make comparative evaluation as fair as possible) and that no safety or discomfort issues are raised during these experiments.

## 2.3 Data collection and assessment objectivesAGILE system evaluation

Data collection will be carried out at Test Case 1 by the local Test Case leader in close co-operation with the WP6 leader to ensure that any deviations can be addressed in time for corrective action in the form of modified or amended data collection. The data collection will include, besides ordinary Test Case sensor measurements, weather data as reported by the local weather stations, info regarding special events, user and operators inputs as logged in the user interfaces to improve the quantitative evaluation accuracy. Operator’s surveillance will also be needed to ensure the uninterrupted collection and reliable storage of measurement data. The raw data will be processed and undergo an initial check for completeness and validity, and, where necessary, data cleaning before being fed into the evaluation process.

Indicators that are going to be used for Test Case 1 (for both sets of experiments) are the following:

- Average Daily Travel Times.
- Average Daily Fuel Consumption.
- Optimality Accuracy.
- Time Required to Complete the LSCS Computations.
- Time Required to Re-configure the LSCS.
- Time Required to Detect a Fault.

In cooperation with the Test Case implementation managers (TCD and FIBP) the following … should be defined for each indicator:

- The maximum and minimum allowable values.
- The European standards related to the particular indicator (if any).
- The data required to measure the indicator.
- The data sources (e.g. which sensors to be used, the particular time-intervals etc.).
- The data analysis (formulas, statistics tests).

During the implementation phase, the operators will observe overall system performance, and in the unlikely event that the AGILE system performance deteriorates, inform the system developer, who will then take any necessary corrective action. Furthermore, the operators – by using the AGILE-SCADA/DCS interfaces – will be able to impose constraints and additional requirements while the AGILE system is operating. Also, special events (e.g. extreme weather or traffic conditions) during the implementation phase which could influence the system behavior will be logged.

Finally, the definition of questionnaires is going to take place, gathering information from the system operators about user comfort and satisfaction as well as the acceptance of the different user interfaces.

### 2.4 Analysis of the users' acceptance

The second part of the evaluation is the analysis of the users' acceptance. Users in this case are both the traffic system (responsible operators) and the end-users (drivers). To gain the views of the both types of users, the following sources will be used:

- Inputs from user interfaces as they are logged in the data base created during implementation.
- Detailed interviews and questionnaires will be conducted with both types of users.
- The data required to measure the indicator.

The prime focus in the interviews and questionnaires will be the effect of the AGILE system operation in their everyday life and time savings, but attention will also be paid to the users' personal judgment of the effect of the AGILE system operation. The elements that are used for the calculation of benefits are:

- Performance improvements during normal operation.
- Performance improvements during abnormal operation (e.g. during AIS experiments).
- Savings in Green House Gas (GHG) emissions.
- Life-cycle assessments.

All of these will be calculated on the basis of the German guidelines for socio-economic evaluation (EWS). On the cost side, there are normally the costs for the system purchase and installation, costs of the system operation as well as the costs for system maintenance; these costs will be held against the expected benefits of using AGILE.

# 3 Test Case 2: Control of an Energy-Positive Building

In order to evaluate a building and its energy supply systems regarding energy efficiency and comfort, the different subsystems for heating, cooling, domestic hot water and electricity need to be evaluated separately. However, the overall investigation needs to bring these values together into an overall building performance assessment.

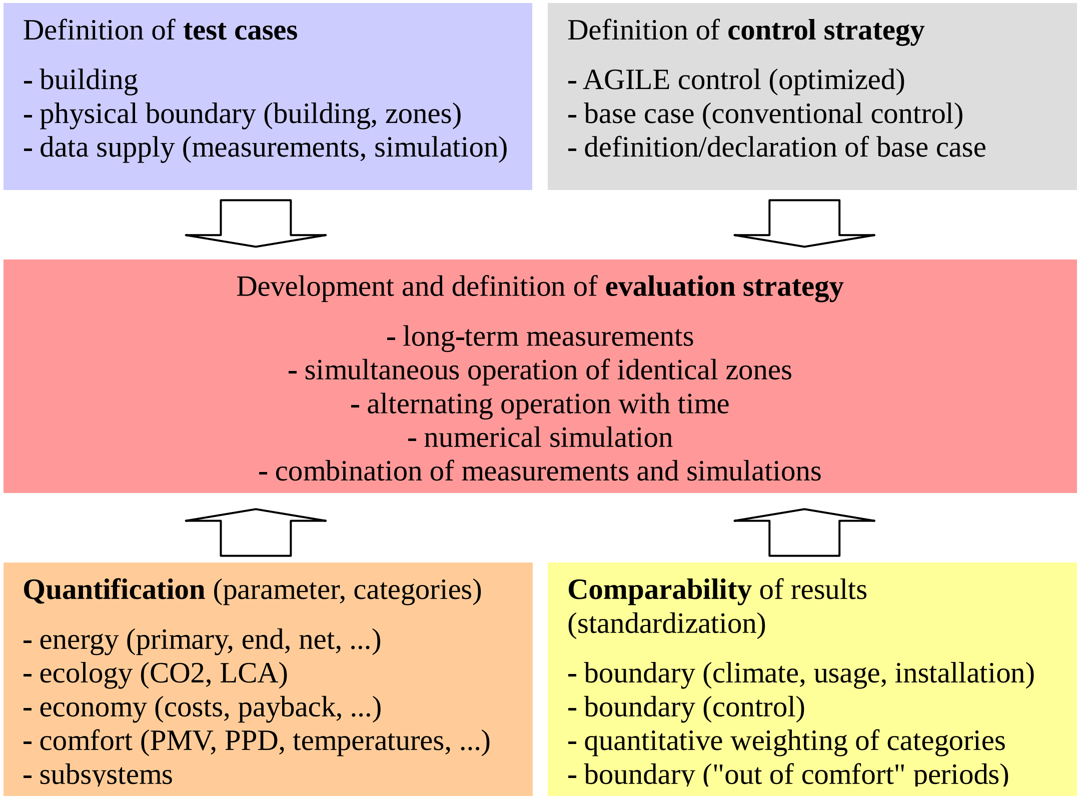
For evaluating both, energy systems and buildings, a definition about type and number of sensors, measuring periods, sampling intervals, and boundary conditions have to be developed.

The scope of this document is the measurement of the improvements provided by AGILE control strategies, permitting a decrease of the consume for the complete building evaluated in different terms, as can be primary energy, CO2, etc.

Within the development of the evaluation methodology several aspects have to be considered, as follows

- Definition of test cases to develop and apply the methodology and additionally give samples. Including definition of test buildings, physical boundary and data supply.
- Definition of the control strategies used for the comparison of the systems, i.e. the optimized AGILE control and the definition/outline of the base case (conventional control or "no control").
- Development of the evaluation strategy itself and the aspects needed in order to rate or benchmark the values, i.e. quantification and comparability.

The next figure gives an overview of these aspects. The structure of the text in the coming section follows the outline given in this figure.



Definition of **test cases**

- building
- physical boundary (building, zones)
- data supply (measurements, simulation)

Definition of **control strategy**

- AGILE control (optimized)
- base case (conventional control)
- definition/declaration of base case

Development and definition of **evaluation strategy**

- long-term measurements
- simultaneous operation of identical zones
- alternating operation with time
- numerical simulation
- combination of measurements and simulations

**Quantification** (parameter, categories)

- energy (primary, end, net, ...)
- ecology (CO2, LCA)
- economy (costs, payback, ...)
- comfort (PMV, PPD, temperatures, ...)
- subsystems

**Comparability** of results (standardization)

- boundary (climate, usage, installation)
- boundary (control)
- quantitative weighting of categories
- boundary ("out of comfort" periods)

**Figure 2: Overview of development of evaluation methodology.**

## 3.1 Definition of test cases

This section describes the definition of test cases to develop and apply the methodology and additionally give samples, including description of test buildings, physical boundary and data supply.

Definition of **test case**

- building ZUB
- physical boundary (building, zones)
- data supply (measurements, simulation)

**Figure 3: Structure of definition of test cases.**

### 3.1.1 *Test Building (ZUB building,Kassel)*

Since the building has been gone into operation in 2001 has already a high level of monitoring due to the more of 700 sensors installed. The performance of the building with its conventional control strategy and design is well known. All energy supply systems as well as most comfort aspects are already monitored. Due to this, it is expected that only a small number of sensors need to be integrated into the building management systems in order to be able to evaluate the AGILE system. However, the number of different energy supply concepts realized in the building is relatively low. This limits the degree of freedom in optimizing the building control and can only lead to an energy efficient building due to its high insulation standard and high inertia of the structure. The south façade and its venetian blinds permit the optimization of daylight and artificial light concept in the occupied zones.

### 3.1.2 *Physical boundary*

The localization of the physical boundary to explore is depending of the situation of the building in general.

The boundary can either surround the

- whole building or
- parts of the building to be defined, i.e. building zones.

For the studied building, the zonal approach is suitable but additionally the whole building can be used as basis for the evaluation data. Since most of the energetic values of the building, e.g. final energy consumption, are only available for the whole building, this possibility is advantageous.

## Definition of zones

The main challenge of the zoning method is the comparability of the results of the defined zones. The similarity is limited due to different situations but should be maximized. In order to get proper results the twin or triplet test cells form a kind of "tower", i.e. they are placed on top of each other on different floors. To decrease the amount of test cells existing in a building that will be evaluated a segmentation in different zones will be made.

The next figure shows floor plans of ZUB. The structure of the different floors enable the choice of similar rooms as is marked in the figure: two rooms on the first and second floor are suitable for the zoning, especially since they are the best monitored rooms in the building. Most of the other office rooms in the building have analogous geometry, thus, extrapolation of the results is possible.

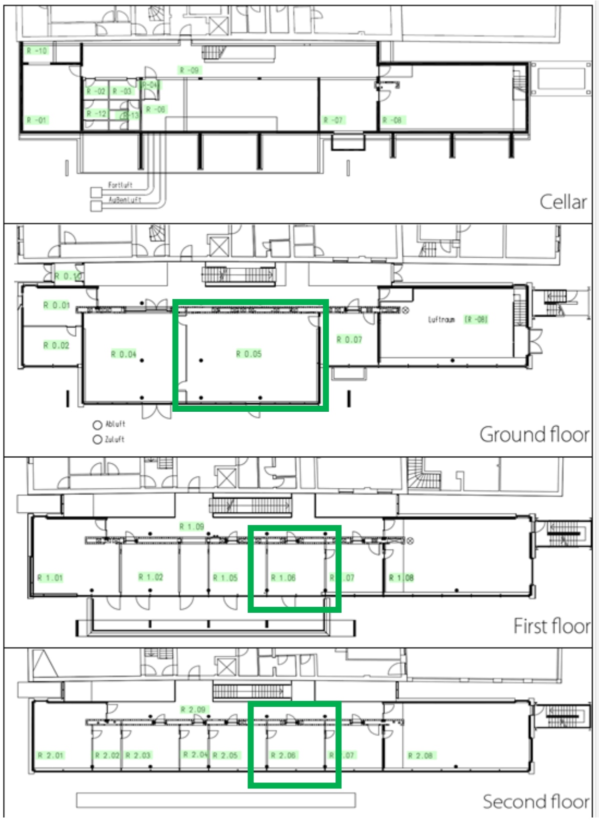


**Figure 4: Floor plans of different stories of RWTH (left) and ZUB (right).**

Equivalent zones will have the following characteristics:

- Common orientation
- Common physical boundary conditions.
    - Same relation windows/wall
    - Same definition of internal walls and its thermal boundaries.
    - Similar depth measured orthogonally to the windows plane.
- Common internal load profiles (similar averages and standard deviations)
    - Occupancy
    - Computers
    - Lighting
- Common control logic and actuators
- Common heating and cooling delivery systems

### 3.1.3 *Data supply*

The evaluation data either base on measurements or calculations, using numerical simulations techniques.

## Measurements

Within the measurements, different optimization potentials for the new control algorithm can be expected. In case of different numbers of sensors and norms considered, Figure 5 illustrates the dependency of the performance improvement on the building equipment. In this example, an improvement of energy efficiency can be caused by:

- Integration of more sensors which enable a more accurate actuator control
- Different limits regarding comfort norms
- Improved and building adjusted control strategies

However, if within building retrofitting, measures like the ones described are mixed, the effect of a single measure like new algorithms is almost impossible to detect only with an overall building monitoring.

The proposed method to evaluate the control's efficiency will compare the results obtained for four different cases:

1. A building equipped with a minimum amount of comfort sensors, and as a consequence of restrictions (typical for office buildings) under basic control strategies.
2. A building equipped with a minimum amount of sensors under AGILE control strategies.
3. A building equipped with a wide amount of comfort sensors/restrictions working under basic control strategies.
4. A building equipped with a wide amount of comfort sensors working under AGILE strategies.

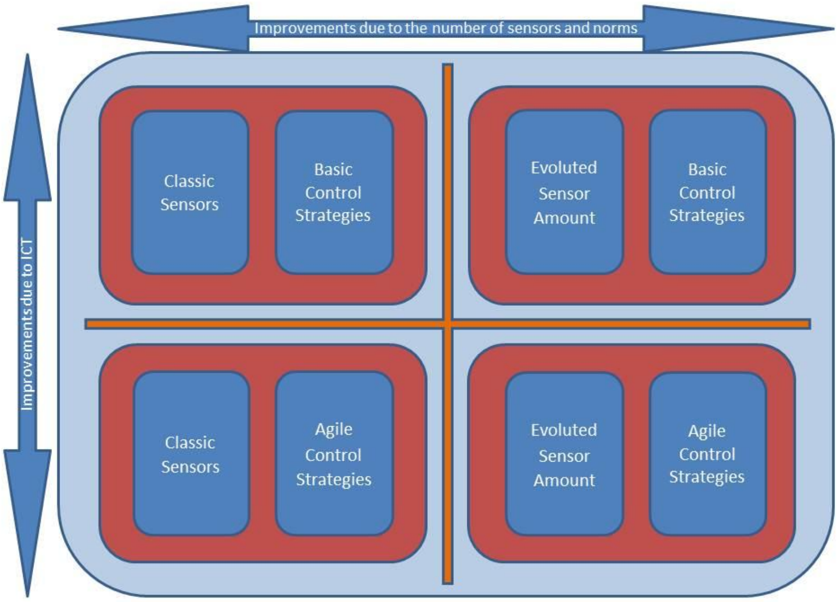


**Figure 5: Comparison diagram for control efficiency based on the amount of sensors**

## 3.2 Definition of control strategy

A definition of the control strategies is required in order to compare the systems, i.e. the optimized AGILE control and the definition/outline of the base case (conventional control or "no control").

Definition of **control strategy**

- AGILE control (optimized)
- base case (conventional control)
- definition/declaration of base case

**Figure 6: Structure of definition of control strategy.**

The optimization of the control for a determinate building inside AGILE project needs of some case definitions used to compare the results obtained after a determinate number of optimization loops.

### *3.2.1 Base case (conventional control)*

For the definition of the base case control ("no control") there are three possibilities

1. The building is managed with basic hysteresis controllers and wide spread generation technologies for cooling and heating as can be fossil boilers and compression chillers that will define a basic set building-generation-distribution. In this case, with a common generation system, the evaluation method will be independent of the technologies installed in the building and the definition of the basic control will be standard, not including the control problems created by a multiplicity of generators.
2. The building is working controlled by a manager in the first step of the optimization process, so the controls implemented are going to be named “No control situation” (step 0) of the optimization. That control parameters will be provided to the simulation software to evaluate the first cost function that will lately compared with the controlled cases.
3. The results of no control for the building are taken from logged data obtained in years of working of the building under similar boundary conditions.

### First possibility

As it has been advanced in the introduction of the chapter, the Basic Control will be independent from the existing generators of the building and their own strategies.

The building will have a simulated demand under certain boundary conditions of utilizability and weather conditions. The sum of all the zonal demands will define the net demand of the building where still it has not been taking into account the distribution losses and the generation.

For the following subsystems there must be a simple definition of baseline performance, which could be as follows:

- A common value of 20% of the total energy demanded as thermal distribution losses will be accepted, fixing the demand to the generators of a 120 % of the final demand.

(Norm describe as an acceptable value for the losses of close to 20% due to emission factors, distribution and losses related to the control).

- For the electrical case, the distribution losses inside the building are consider as negligible.

For the case of generation systems, it will be accepted as basic systems.

- Gas Boilers with stationary efficiency of 90%
- Electrical air to air chillers with an electrical COP of 3.5
- Primary energy factor of the gas 1.1.
- Natural gas with 39900 kJ/kg as heating value
- Primary energy factor of the electricity aprox 2.4 (Depending on the country)
- 230 gr $CO_2$ /kWh Natural gas. =0.0638 gr $CO_2$/kJ Natural gas

## Second possibility

The manager of the facility set the first control parameters, so the primary energy factors, and efficiencies of the particular system depends on the composition of the generation and distribution technologies installed in the building.

Once collected parameters of the particular case, they must be introduced into the simulation program with the control logic detailing the generation priorities in the case of various distribution and generation systems.

### *3.2.2 Optimal Control Situation (AGILE)*

It is defined by the mathematical limit of the parameters described in one of the following sections. After multiple simulations with different controls the savings, primary energy demands will reach a point where further optimizations are impossible. In these cases GCEI will be one, noticing the reach of the objective. A parameter based in CO2 emission must not necessarily get a GCEI equal to the unit because GCEI measures how close a control strategy is from the economical optimal that must not be the same of the best control to decrease the contamination created by the use of fossil fuels.

During the development of the project, new optimizations will move the results to increased efficiencies and lower consumes that makes obligatory a definition of the optimal given by an iterative process of increased efficiencies that will converge to a value. The sequence of values will have a limit that for us will be the optimal result of the control.

Although the optimal must be the control strategy that optimizes a function or an evaluation parameter, not all of them reach the optimum for the same inputs.

- Economy functions depend on the regional/national prices of the energy.
- $CO_2$ savings depends on the technologies installed or fuels consumed and the fraction of fossil generation inside the electricity and thermal energy bought to the grids.
- Primary energy unit comparison ($kWh_{Prim}$) is dependent on the generation efficiencies of the machinery installed under variable working points.

The existence of different parameters that evaluate the building and its installed systems also forces the definition of the “leading” parameter or the group of them (and the weights in an optimal function) that defines the optimum.

The authors propose a definition of the optimal control based on primary energy or $CO_2$ emissions that are comparable for every building that could be evaluated with this methodology. Once the result is reached, the conversion to monetary units and payback times can be done to evaluate the economic viability of the project and measurements taken.

### 3.3 Quantification (parameter, categories)

In order to evaluate the performance improvement of a new control strategy, the main challenge is to define the performance criteria used and the base-case to compare with. Regarding the performance criteria different values can be assessed in order to realize different "points of view". The main aspects concern energy and comfort, additionally ecology (e.g. emissions) and economy must be considered. Other aspects could deal with humidity (protection of construction), acoustics (sound protection, e.g. loudness of fans/pumps), safety (burglary protection) and health (user protection).

**Quantification** (parameter, categories)

- Energy (primary, end, net, ...)
- ecology (CO2, LCA)
- economy (costs, payback, ...)
- comfort (PMV, PPD, temperatures, ...)
- subsystems

**Figure 7: Structure of quantification of parameters/categories.**

The following figures contain polar diagrams with sample values to visualize the simultaneous results of different aspects for the different systems in order to compare all categories at the same time.

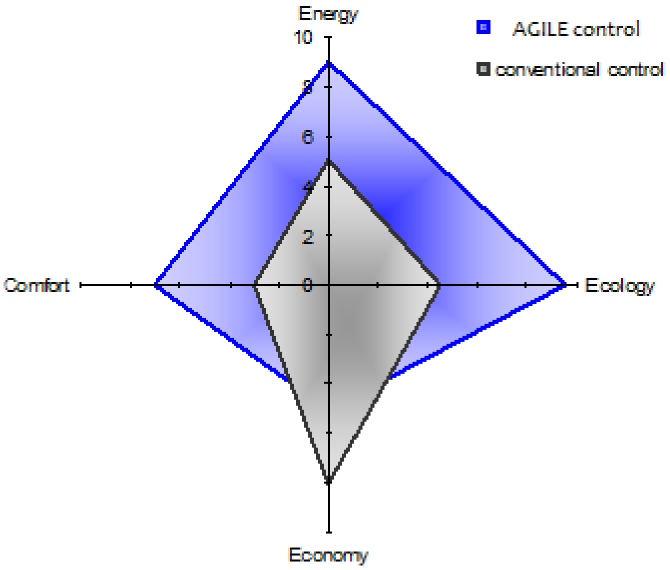


**Figure 8: Weighting of quantification parameters (categories) and comparison of the systems - resulting values for main categories.**

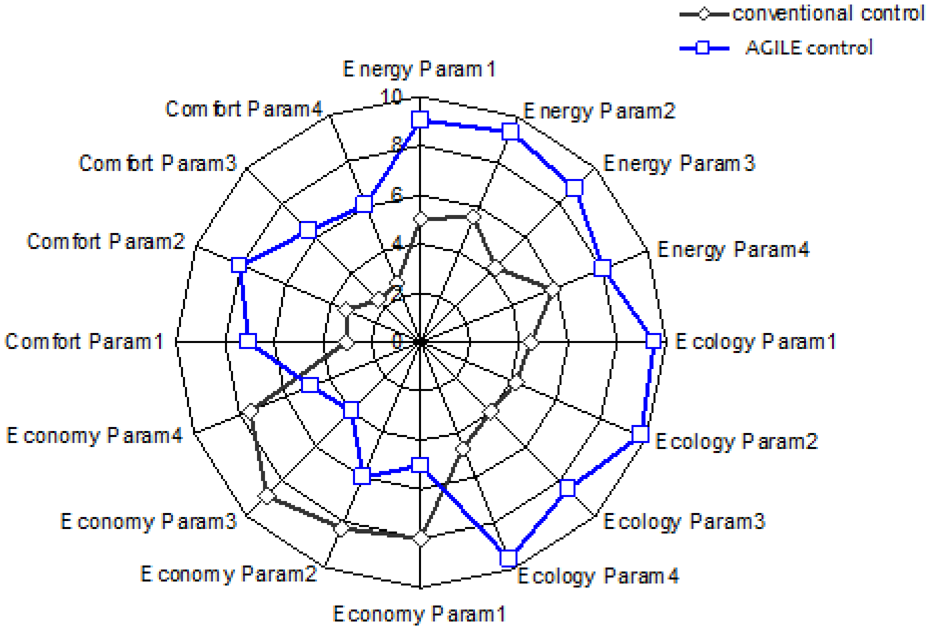


**Figure 9: Weighting of quantification parameters (categories) and comparison of the systems - several values for main categories.**

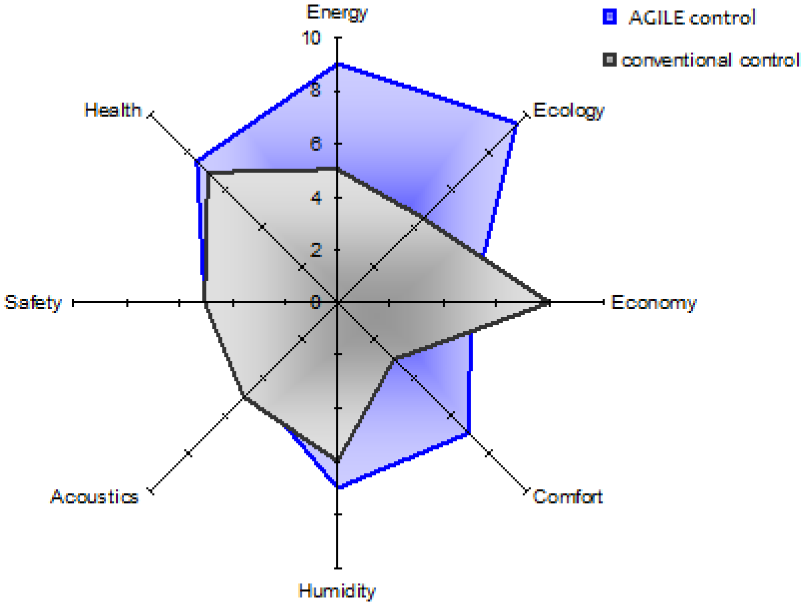


**Figure 10: Weighting of quantification parameters (categories) and comparison of the systems - extension of categories.**

If only looking at energy related values, end-energy consumption or primary energy consumption would be most appropriate. In case of on-site energy generation, parameters like net energy consumed are required. However, building control systems need to provide an indoor climate within a fixed comfort range regarding temperature, humidity, noise, air flows, etc. Usually, exceeding of these limits is accepted for a few hours within a year. With respect to temperature, the definition of degree-hours for exceeding the temperature limits is often used. These degree hours can be then integrated into the objective function of energy consumption minimization.

For the building, two different ways of evaluation will be considered:

- Based on the comfort conditions in the buildings and user-acceptance of the occupants.
- Based on the energy demanded/consumed by the building.

However, both ways need to be brought together in the final evaluation of the AGILE system, since improving one indicator usually leads to a degradation of the other indicator.

### *3.3.1 Comfort Based*

Norm EN 13779 defines the comfort parameters that should be kept for different levels of indoor quality. Here, not only the particles contaminating the air or $CO_2$ levels are indicated, but also the thermal comfort depending for example on air temperature inside living zones, temperatures of the surrounding walls, humidity, air speed, clothing factors and ambient quality for different works or domestic conditions. (Lighting, noise level, ...).

The sensations of the people that “live” the building will also be taken into consideration and need to be compared to the indoor comfort evaluation. If appropriate, the user demands will be used as an input for control strategies.

### *3.3.2 Energy Based*

The complete buildings need to be evaluated including their energy generation systems (both renewable and non-renewable), distribution and delivery systems. This all then leads to the building demand, which strongly depends on the used control strategies. For enabling the evaluation, every piece or subset need to be evaluated separately in order to be finally treated as a complete set.

The European Committee for Standardizations CEN (Comité Europeén de Normalisation) propose the adoption of a determinate structure when evaluating the building demands and primary energy needs in terms of energy and climate impact ($CO_2$ Tons).

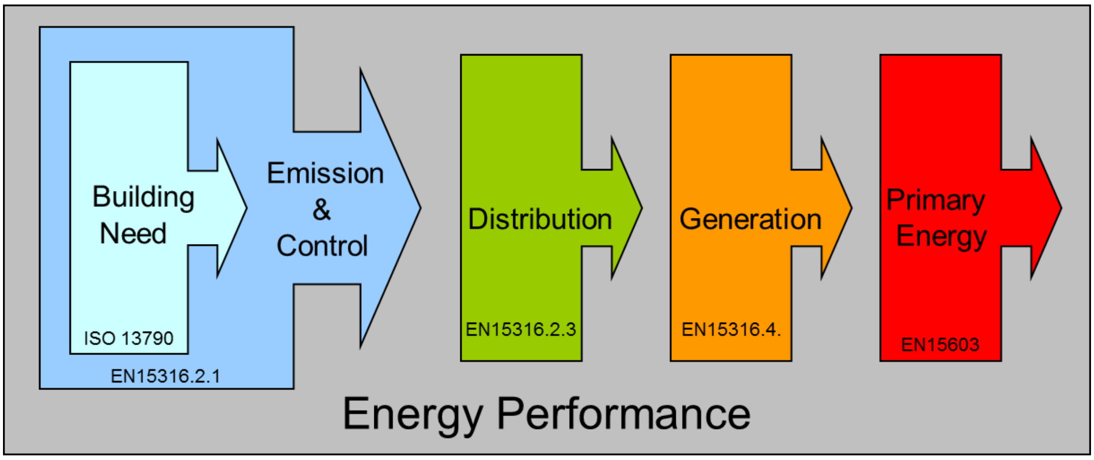


**Figure 11: Evaluation of the energy performance**

As can be seen in the **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, CEN and ISO norms start the energy performance evaluation of a building from its demands, passing through the delivery systems that effectively condition the zones, over the distribution systems delivery energy to the different zones, the generation systems providing the energy until the evaluation of the primary energies needed to fulfill the building needs. An optimization of the building needs to look at all steps within this chain in order to reduce primary energy consumption and CO2 emissions.

The building demand is the net energy that will correspond to the 100% of useful energy delivered to condition the thermal zones and is only affected by the sum of different thermal losses and gains as well as the desired comfort conditions but independent on the generation and supply systems. Due to this, it is the base to “count” the energy quantities at play in the complete system, but it cannot be measured directly.

The second step of the analysis will be the emitters and control strategies. Delivery systems like fan coils, radiators or thermally activated building element deliver heat/cold to the zones. This energy amount will cover the demand with an efficiency that will depend on the terminal system and the accuracy of the control strategies to reach the set points.

The third stage includes the energy losses through the distribution system in the building. Here different aspects need to be considered depending on air based or liquid based energy supply systems as well as whether the energy is generated centralized or decentralized. In addition, electricity consumption for pumping and ventilation need to include into the energy balances.

The fourth stage takes into account the generation losses from the production of heating, cooling and electricity in the different generation units.

Finally, the primary energy required to produce the energy to be generated and delivered to the whole chain need to be considered. Hereby, the amount depends on the type of the generation systems as well as on the specific location/country.

## 3.4 Comparability of results (standardization)

The unique way of comparing the controls on the same building is keeping constant the boundary conditions for the compared cases. It means, in terms of comfort, that if the building has only a typical finite amount of sensors that only permits the control on the ambient temperature without taking into account lighting, humidity…, the same rules will domain the problem under AGILE conditions.

**Comparability** of results (standardization)

- boundary (climate, usage, installation)
- boundary (control)
- quantitative weighting of categories
- boundary ("out of comfort" periods)

**Figure 12: Structure of comparability of results (standardization).**

The comparison among the results obtained will permit the evaluation of:

- Results obtained when a different number of comfort parameters (norms) are used. (Energetic implication of the comfort boundaries)

- Results obtained with AGILE advanced controls against the primarily installed ones.
- Results obtained with AGILE advanced controls when different comfort conditions must be kept. (Energetic implication of the comfort boundaries for optimized controls)

After the definition of the "Production parameters" that must be evaluated to check the efficiency of the AGILE measurements, questions appear on the way of estimating the yields of the systems before installing the new control protocols and the maximum efficiency that can be reached with an optimal control.

The quality of the control strategies must be done under the same boundary conditions for every one of the cases, and there are external parameters that cannot be forced to a predetermined value as can be the radiations, external humidity and temperatures … that make feasible the comparison among the results.

The internal boundary conditions for a "comfortable work" of the building are fixed by the values appearing in the resuming table of the chapter 4 ensuring compliance of zonal comfort conditions during the occupancy periods (category 2).

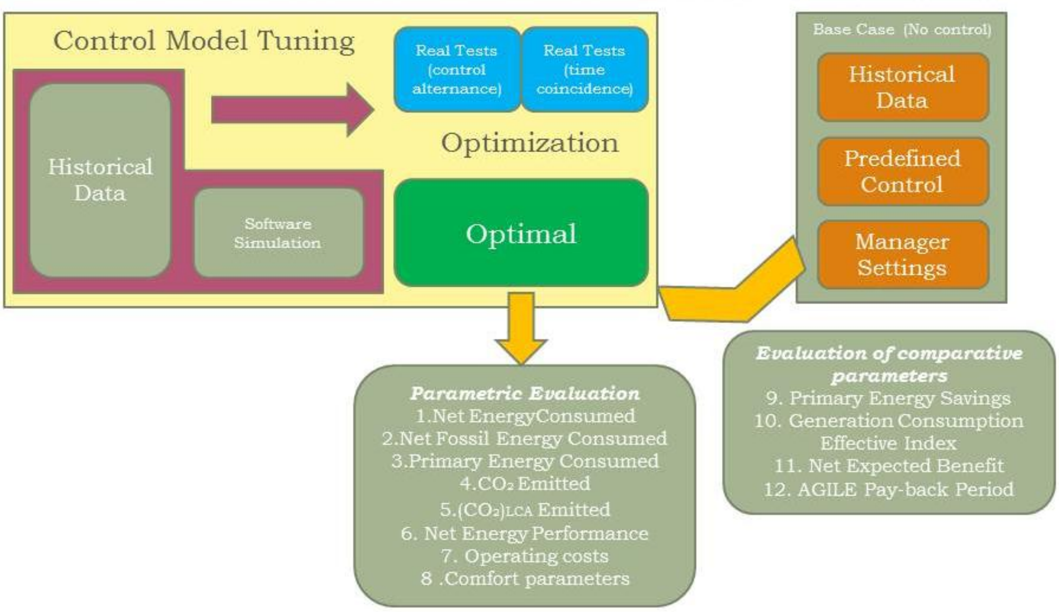


**Figure 13: Control schema needed to evaluate AGILE performances**

### 3.5 Development and definition of evaluation strategy

Finally the development of the evaluation strategy itself is required and the aspects needed in order to rate or benchmark the values, i.e. quantification and comparability.

Development and definition of **evaluation strategy**

- long-term measurements
- simultaneous operation of identical zones
- alternating operation with time
- numerical simulation
- combination of measurements and simulations

**Figure 14: Structure of development and definition of evaluation strategy.**

All the evaluation options pass through three different possibilities:

1. Simulation of control strategies under the same boundary conditions using software, with possible problems on the accuracy of the models.
2. Testing buildings and strategies in alternating time periods with the same averaged boundaries. i.e: The results obtained in various different (probably consecutive) time periods can be compared if the averaged values of the external parameters are similar and the variable's time development has the same profiles with problems in the definition of “similarity“ of variables and profiles. In this case the sensibility of the building under different average values and amplitudes of the external variables must be controlled and defined.
3. Time-matched of different control strategies in similar test cells representative of a considerable area of the building (in the case that the building have comparable zones to evaluate the partial results obtained). In these cases, loads and boundary conditions of the representative cells must be verified to assure the utilizability of the results.

After the exposition of the possibilities, it is feasible a combination of different situations:

- If there are no possible common zones in the building (Case 3), a combination of the two first possibilities will permit the setting of the simulation model with parameters collected from alternative test periods. First steps of this combined method will last longer because of the need of data to tune the simulations, but after some weeks of testing the simulation will be able to run quicker with certainty of accuracy, letting the manager test in virtual mode the limits of the improvements expected.
- In the case of buildings that have data collected from long enough operation periods, the combined seasons of testing control algorithms in the reality with the simulation can be skipped by a tuning period of the simulation software with historical data.
- If similar test cells can be identified (Case 3), a comparison of the results obtained under different control actions combined with simulation results will create a feasible opportunity of decreasing the time assigned for testing periods.

With respect to this, a clear base-case definition is necessary, which needs to be different for each investigated building. Base-cases, which can refer either to the whole building or to limited numbers of rooms and zones, can be:

- Long-term operation performance with conventional control strategy
- Instantaneous building operation with conventional control strategy but new sensor installations, new indoor climate limits and new technical installations
- Simulated base cases

With respect to this, evaluation strategies can be:

1. **Longer-term** performance measurements of new and old control strategies **of the whole building**
2. **Simultaneous** and comparative performance **measurements of identical building zones** (same geometry, same internal and external loads, etc.) within a building in which one zone is operated with a conventional control and one zone with the new improved strategy
3. **Alternating operation of the complete building** (or building zones), e.g. for a complete week, with old and new control strategies
4. **Numerical investigations** of the performance with old and new strategies using dynamical system simulations, either on a zonal perspective or with respect to the whole building including all building services
5. **Combinations of measurements and simulations**, in which the building is simulated using one control and in real-time measured using the other control.

However, the accuracy of each procedure needs to be considered for the different situations. Hereby, the comparability depends on the different situations in terms of different use of the building, different weather situations, and possibly different building service systems. Only if the influence of these parameters on the performance indicators is significantly lower than the effect of improved control strategies, the suggested procedure can be used to evaluate the performance improvement.

### *3.5.1 Long-term measurements*

For this, an estimation of the similarity of the use of the building, the building services and the weather situations over the years is required. In case of changes occur after the installation of new control strategies, the impact needs to be calculated, e.g. using simulation methods.

### *3.5.2 Simultaneous operation of identical zones*

Here, the two building zones need be selected according to minimal differences of for example zone orientations, dimensions and building use. For this, the impact of these differences usually remaining outside of laboratories needs to be calculated.

### *3.5.3 Alternating operation with time*

As for option 1, the similarity of the use of the building and the weather situations need to be considered. In addition, the dynamic behavior of the building and the respective effect on the alternating building operation influences the comparability. In order to minimize the effect of this, a high number of alternating states (weeks or months) need to be integrated in the evaluation.

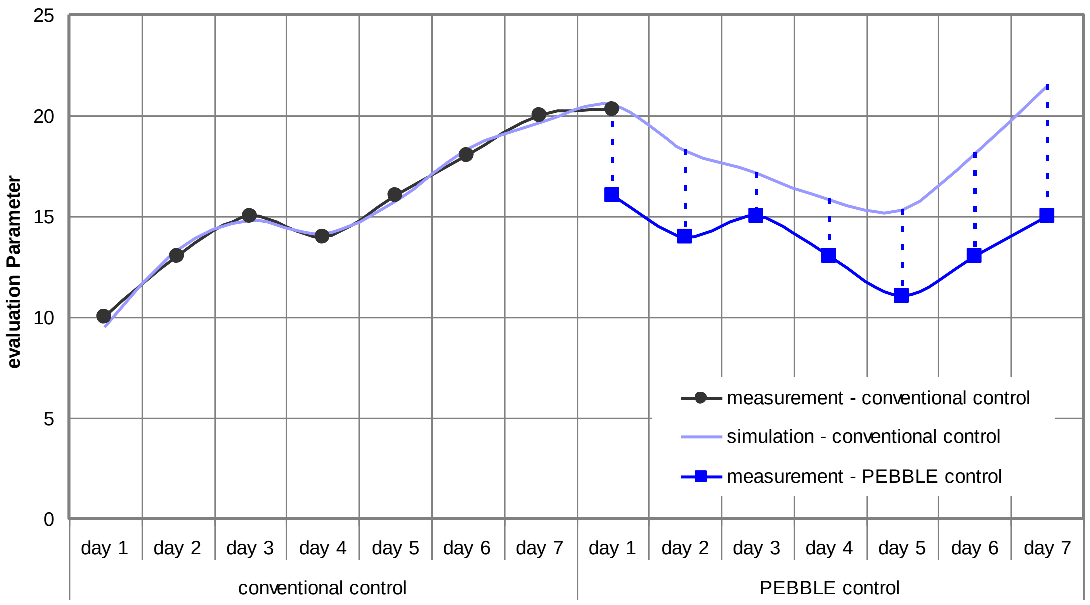


**Figure 15: Sample results for alternating operation of two weeks.**

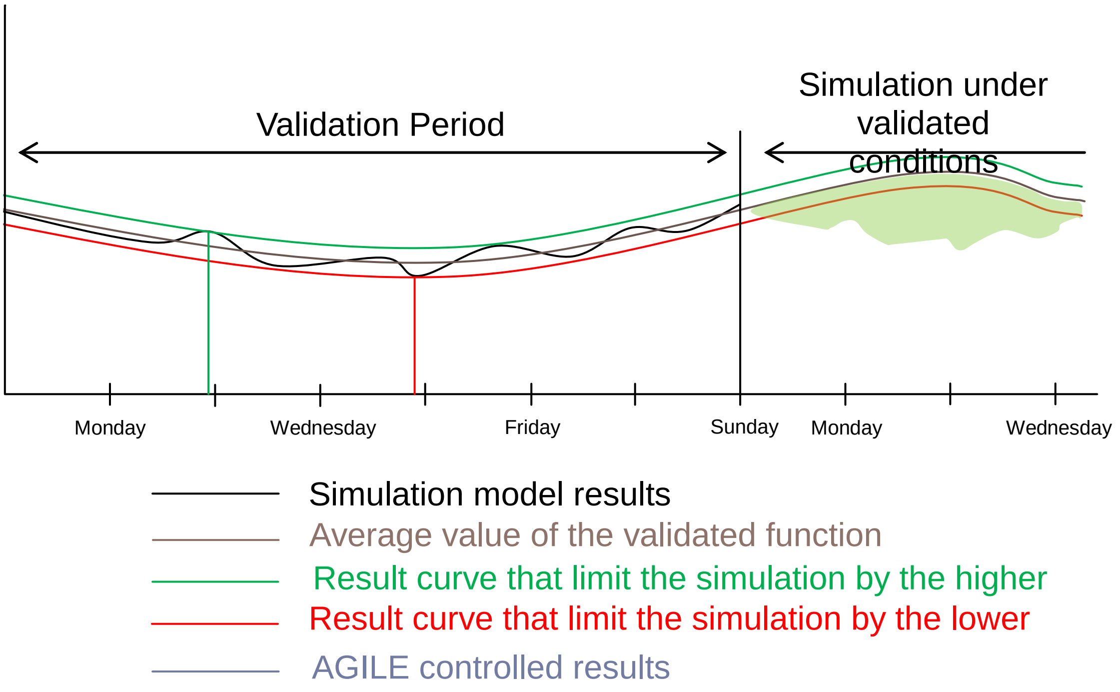


**Figure 16: Sample results for alternating operation of two weeks.**

### *3.5.4 Numerical simulation*

Numerical simulations using dynamic simulation programs like TRNSYS can help to identify performance differences with control strategies, since all boundary conditions can be kept identically. However, simulation tools and models are often limited in their accuracy and especially control strategies are different to be implemented.

### *3.5.5 Combination of measurements and simulations*

The combination of measurements and simulations is a very attractive solution. However, in order to achieve identical results for simulations and measurements a lot of effort in adjusting the simulation models is needed. Thus, following the argumentation of 4, the possible deviations within the simulations must be considered for the performance evaluation of new control strategies with this procedure.