ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome IX [2016] , Fascicule 2 [April – June]
ISSN: 2067 – 3809

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MODELING OF THE BUILDING THERMAL BEHAVIOUR USING NONLINEAR SYSTEM IDENTIFICATION

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Abstract: Model-based predictive control is a very modern powerful control strategy that uses a model of the plant to predict its future behaviourand has been in focus of researchers in the area of buildings energy management. The aim of this paper is to develop and analyze NARX (Nonlinear AutoRegressive with eXogenous inputs) structure for the modeling of the building thermal behavior. A database was generated using simulation in EnergyPlus software. The NARX identification model was designed using the MATLAB System Identification Toolbox. The input variables analyzed in this paper are: outdoor temperature, heating or cooling power, and direct solar radiation. Simulation results demonstrate that the proposed nonlinear structure can be effective identificationtool for development of nonlinear buildings predictive control.
Keywords: building, NARX, identification, thermal behaviour

INTRODUCTION

Model predictive control (MPC) has been in focus of researchers in the area of buildings [1]. Model predictive control denotes a wide range of control techniques which apply a model to the prediction of future system behavior and calculate the control signals through the optimization of the objective function. The basic conditions that each model should satisfy are practical simplicity, well estimated system dynamics and satisfactory prediction properties.

Various deterministic approaches which uses knowledge of the structure and physical and material properties of a building and statistical procedures have been applied in order to derive a total model for the heat dynamics of a building.Deterministic models are based on energy and mass balance integral–differential equations and development of such type of model is a very time consuming task.

Prívara et al. [2] proposed a new methodology to obtain a model combining the building energy performance simulation tools and statistical identification. Bacher and Madsen [3] applied the procedure for identification of the most suitable grey-box models for the heat dynamics of a building on the basis of data from an experiment and prior physical knowledge of the system. Also, the grey box modelling method has been applied to derive a total model for the heat dynamics of a building by Andersen et al. [4]. Jiménez et al. [5] have been presented the application of the MATLAB System Identification toolbox to estimate the thermal properties of building components from outdoor dynamic testing, imposing appropriate physical constraints and assuming ARMAX parametric models.The nonlinear black-box models perform better than linear models (ARX, ARMAX) in predicting buildings thermal behaviour [6-9].

The present paper suggests a procedure for identification and development NARX structure for the modeling of the building thermal behaviour. A database has been generated using simulation in EnergyPlus software.

METHODS FOR NONLINEAR SYSTEMS IDENTIFICATION

Different methods have been developed in the literature for linear system identification. These methods use a parameterized model. The parameters are updated to minimize an output identification error.

The linear dynamic systems with an input u and an output y can be described by the ARX (**A**uto **R**egresivee **X**ogenous) model:

$$y(k)=\varphi^{T}(k)\theta=\theta^{T}\varphi(k) \qquad (1)$$

where: $y(k)$ is the output of the model, $\varphi(k)$ is the regression vector and θ is the parameter vector.
The regression vector ARX structure is:

$$\varphi^{T}(k)=\{-y(k-1),-y(k-2),-y(k-3),...,-y(k-n_a)$$
$$u(k),u(k-1),u(k-2),u(k-3),...u(k-n_b)\}$$

andthe parameter vectoris

$$\theta^{T}=\{a_1,a_2,...,a_{n_a},b_1,b_2,b_3,...,b_{n_b}\}.$$

A wide class of nonlinear dynamic systems can be described by the Nonlinear ARX model:

$$y(k)=f(\varphi(k),\theta) \qquad (2)$$

where: f is a nonlinear function whose Inputs are the model regressors.
This block diagram of a nonlinear ARX model is shown in Figure1.
The nonlinearity estimator block is combine with linear and nonlinear function in parallel and maps the regressors to the model output:

$$f(\varphi)=L^{T}(\varphi-m)+r+g(Q(\varphi-m)) \qquad (3)$$

dis a scalar offset, m is the mean of the regressors, Qis a projection matrix.

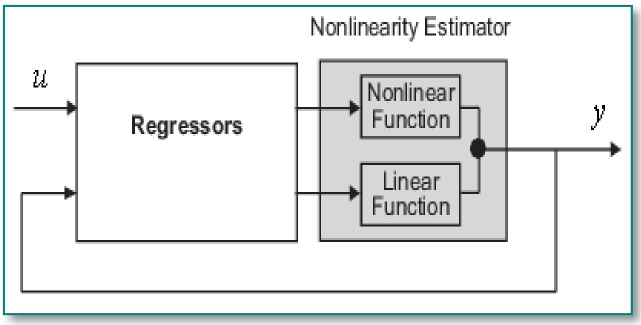

Figure 1. Structure of Nonlinear ARX Models.

The wavelet network can be trained to approximate function g as:

$$g(\varphi)=\sum_{i=1}^{n}\alpha_k\kappa(\beta_k(\varphi-\gamma_k)) \qquad (4)$$

where: $\kappa(*)$ is the wavelet function, n is the number of nonlinear units and α_k, β_k and γ_k are constant.

BUILDING SIMULATION

The analyzed building consists of three zones, Figure 2.
Basic file description: 1 story building divided into 3 interior conditioned zones. Roof with no plenum. No ground contact with floor. Floor Area: 130.1 m^2. There is a single window in the west zone south wall. An electric low temperature radiant system is used for heating the floor of each zone, with power ratings of 12 kW, 8 kW and 8 kW for the north, west and east zones respectively.

The ambient air temperature profile was of Chicago, IL, USA. The disturbances due to internal heat gain and solar heat gain were different for every zone and time-varying.
In this case study, we used the EnergyPlus model as the ground truth for the building, i.e., it was considered as the "real" building. The program EnergyPlus 6.0 is used, which allows the simulation of thermal behavior of buildings during the analyzed period.

SIMULATION RESULTS

In this work, NARX (Nonlinear AutoRegressive with eXogenous inputs) structure are chosen to predict zone temperature (North, West and East). The procedure for determining proper NARX models from EnergyPlus data involves three steps: (1) obtaining input-output data by simulating (2) model structure selection (train NARX with different delays), and (3) model validation. The input vector of the considered models is:

$$\boldsymbol{u}=[T_e\ P_{hc}\ R]^{T}$$

where: T_e is outdoor temperature, P_{hc} denote heating or cooling power and R is direct solar radiation.

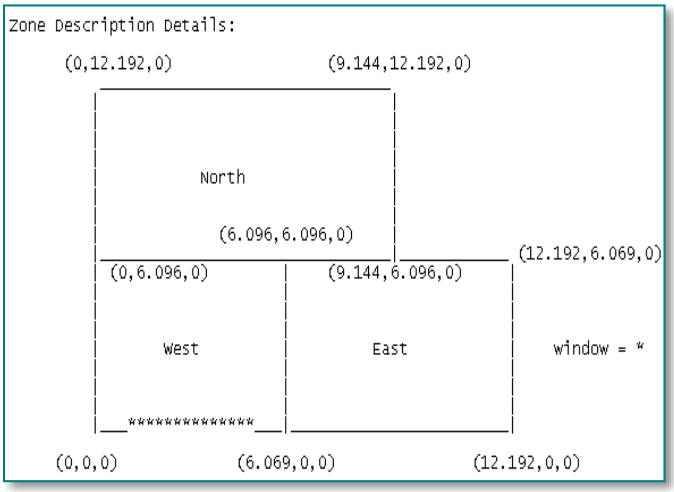

Figure 2. The analyzed building.

The number of the NARX inputs is determined by the input and output lags. In this paper, the satisfactory accuracy is obtained for regression vector:

$$\varphi^{T}(k)=\{T_i(k-1),\ T_e(k-1),\ P_{hc}(k-1),\ R(k-1)\} \qquad (5)$$

The numbers of units wavelets estimator have been automatically chosen by the estimation algorithm.
This section presents the results of simulations for the west zone.
The wavelets estimator for prediction WEST zone temperaturehas94 units.
The time series of the inputs and output variables are shown in Figure 3, Figure 4, Figure 5 and Figure 6.

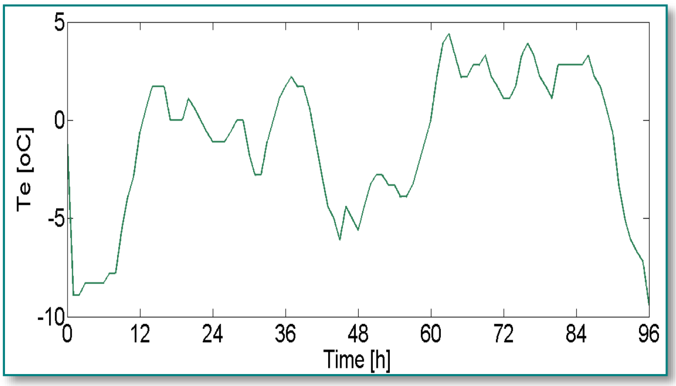

Figure 3. The outdoor temperature.

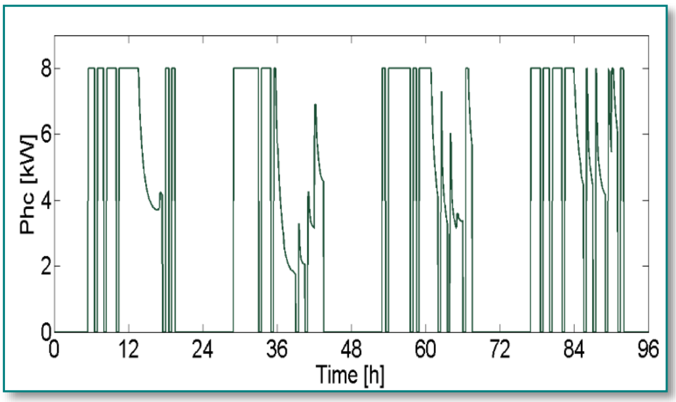

Figure 4. The power heating or cooling.

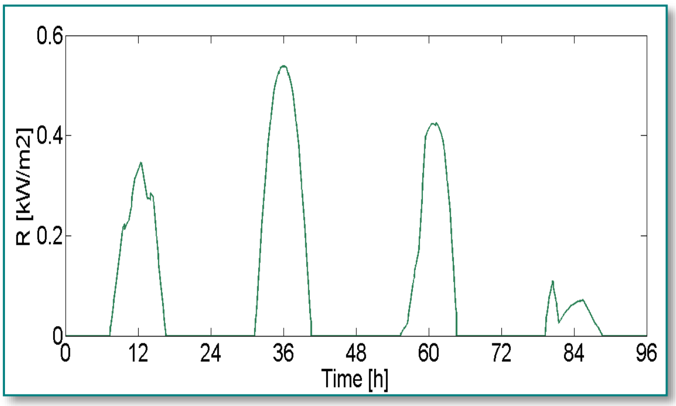

Figure 5. The direct solar radiation.

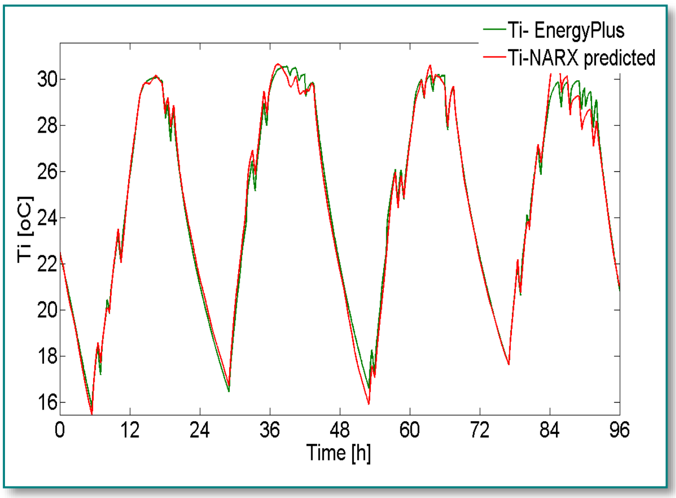

Figure 6. The indoor temperature.

CONCLUSION

In this paper, a procedure for using MATLAB System Identification Toolbox for modeling building thermal behavior is proposed. NonlinearARX model is more suitable than the linear estimator because room temperatures is governed by nonlinear equation. The result of the simulation show that NARX model predicted values are in accordance with the values obtained by the simulation.

The future research should include the application of the proposed technique on a real input–output data collection from measurements.

ACKNOWLEDGMENT

Research presented in this paper was supported by Ministry of Science and Technological Development of Republic of Serbia, Grants TR 33015 and III 42006.

Note

This paper is based on the paper presented at The 12th International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology – DEMI 2015, organized by the University of Banja Luka, Faculty of Mechanical Engineering and Faculty of Electrical Engineering, in Banja Luka, BOSNIA & HERZEGOVINA (29th – 30th of May, 2015), referred here as [10].

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ISSN:2067-3809