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Dynamic Methods for Building Performance Assessment.

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ABSTRACT

About 40% of the energy consumed in Europe is in the building sector, mainly for ventilation, heating and cooling purposes. Therefore it is important to achieve a proper assessment of thermal characteristics of building components (such as windows, walls etc.) under real conditions. Innovative and often complex façade construction elements require a careful study of their energy characteristics. Dynamic ventilated walls or building integrated photovoltaic elements are a few examples.

Dynamic analysis methods are techniques to analyse dynamic processes and to identify typical parameters of the physical process. Dynamic methods take into account the aspect of time whereas a static analysis method does not. By dynamic evaluation techniques (parameter identification) dynamic effects due to accumulation of heat in the installation, test room envelope and test specimen are properly taken into account. In general, parameter identification is needed to be able to derive the steady state properties from a short test with dynamic (e.g. fluctuating outdoor) conditions.

The application of system identification techniques to the energy performance assessment of buildings and building components requires a high level of knowledge of physical and mathematical processes. This factor, combined with the quality of the data, the description of the monitoring procedure and test environment, together with the experience of the user of the analysis software itself, can produce varying results from different users when applying different models and software packages. Past international system identification competitions demonstrated the spread in results that can be expected regarding the application of different models and techniques to the same benchmark data. The DYNASTEE - PASLINK network has attempted to consolidate and strengthen knowledge and expertise of system identification techniques within the grouping by organising lectures and workshops and also to ensure that data analysis meets minimum quality levels.

The paper highlights the milestones in the development of practical software tools, defining data series for training and selected practical case studies. In order to maintain the quality in analysis and modelling work a third System Identification Competition has been organised.

In parallel with the system identification analysis techniques, model calibration and scaling procedures have been developed that make use of the experimental data to formulate simulation models of the building components and then apply them to full-scale application. Over the last 10 years, dynamic simulation programs have improved in functionality and are becoming more routinely used in design and energy performance compliance checking of buildings.

Conclusion

Dynamic mathematical technology is recognised as crucial in optimisation of energy efficiency. Integration of renewable energy technologies in our society is rapidly taking place giving another perspective of the use of available energy resources. The expertise available in the present DYNASTEE - PASLINK Network can be deployed in particular in the field of dynamic testing, analysis and simulation methods. This is a challenge which the grouping will take by fitting it into the political requirements for building energy research.

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The DYNASTEE Network

Over the years, the Grouping of Outdoor Test Centres (formerly PASLINK EEIG), has actively supported activities and initiated European research projects related to the energy performance assessment of buildings. A real experimental set-up for the outdoor testing of building components provided high quality dataseries for the estimation of thermal characteristic parameters. Often statisticians and mathematicians do not have the technical knowledge to correctly apply dynamic analysis techniques to physical processes, whilst engineers may not have adequate knowledge of the complex statistical and mathematical processes. The objective of DYNASTEE is therefore to provide a multidisciplinary environment, by bringing together the scientific community in the field, to add further momentum to many years of applied research, to identify feasible approaches for the practical implementation of dynamic techniques, and to install the necessary continuity for a cohesive approach to the research work related to the energy performance assessment of buildings in relation to the EPB Directive.

The DYNASTEE network aims to provide a forum for the study of the above mentioned themes by creating an environment of scientific collaboration and awareness, bringing together the scientific community in the field, and adding further momentum to many years of applied research, thus bringing ideas into application.

Introduction

Global political interest in a more environmentally-conscious use of available energy resources came into the spotlight during the nineties. The White Paper [2], the Green Paper [3] and the Kyoto Agreement [4] are well known to all. More and more interest in solar technologies became evident and the market for solar collectors and photovoltaics was growing fast. The grouping profiled itself as a scientific community of experts on Testing, Analysis and Modelling. After ten successful years of European collaboration, the PASLINK EEIG started a new project on the application of photovoltaic technologies in the building envelope. This project, PV-HYBRID-PAS, aimed to study the overall performance assessment of this specific integrated technology in buildings. The use of the outdoor test facilities in several Member States situated in different climates, together with the available expertise on analysis and simulation techniques, offered the ingredients for a successful project. Several other projects were started, for example IQ-TEST, DAME-BC and the expertise of the grouping was also offered to other European projects, such as ROOFSOL, PRESCRIPT, IMPACT and PV-ROOF.

The advancements in computer software and hardware were creating an environment for improved software tools for analysis and simulation. Several system identification competitions were organised to develop the level of skill for dynamic analysis methodology. Nowadays dynamic calculation methods are much user-friendly and more reliable to apply.

European policy takes into account evidence of changes in global climate and is adapting its policy to reduce energy consumption and to stimulate the use of renewable energies up to 20% by 2020. It does so by defining a number of Directives, many more than the Construction Products Directive in 1989 [1]. The development of standards and national regulations is expected to contribute to achieving the goals set in the White Paper. The Directives cover the topics of energy efficiency [5], electricity from renewable energy technologies [6], energy labelling [7], energy performance of building [8], cogeneration, etc. Increasing interest in research in energy technologies that result in the rapid transformation into a sustainable and secure energy future for Europe, together with further advancements in information technology (internet, fast computers and portable platforms), herald many opportunities for European research and industry. The grouping offers its expertise and investigates the means to evolve through support of activities which adopt a global approach to energy and environmental design in the built environment, including the DYNASTEE network, thus preparing for the changes in the next ten years.

What are dynamic methods?

Considering the thermal energy demand in the built environment, the main parameters of interest in the research area of energy in buildings are the thermal transmittance and the solar aperture as defined below. Whilst these parameters can be derived from tests with a relatively long duration using the averaging method, commonly used in laboratory experiments, the use of dynamic test sequences and dynamic system identification techniques can reduce the test period and improve accuracy. Such powerful methods for the identification of physical parameters can enable the construction industry to optimise their products for the efficient use of solar energy and to fulfil legislative requirements, like energy labelling.

Dynamic analysis methods are techniques to analyse dynamic processes and to identify typical parameters of the physical process. Dynamic methods take into account the aspect of time whereas a static analysis method does not. By dynamic evaluation techniques (parameter identification) dynamic effects due to accumulation of heat (in the case of buildings, due to thermal mass) in the equipment, test room envelope and test specimen are properly taken into account. In general, parameter identification is needed to be able to derive the steady state properties from a short test with dynamic (e.g. fluctuating outdoor) conditions and assess time dependent parameters.

In analogue with electric components one may say that steady state situation are dealing with resistances only, whereas applying dynamic methods can deal with resistances and capacitances. In addition dynamic mathematical techniques can deal with uncertainties in available data, like sudden changes.

The application of system identification techniques to the energy performance assessment of buildings and building components requires a high level of knowledge of physical and mathematical processes. This factor, combined with the quality of the data, the description of the monitoring procedure and test environment, together with the experience of the user of the analysis software itself, can produce varying results from different users when applying different models and software packages. Past international system identification competitions (1994 and 1996) demonstrated the spread in results that can be expected regarding the application of different models and techniques to the same benchmark data. The PASLINK network has attempted to consolidate and strengthen knowledge and expertise of system identification techniques within the grouping by organising lectures and workshops and also to ensure that data analysis meets minimum quality levels.

The test methodology and analysis methods in the early days of the PASLINK network were based around steady state evaluations. However, as the project progressed it became increasingly clear that both dynamic testing and analysis methods were required to deliver high quality performance characteristics for building components tested in real climates [9]. During the '90's the PASLINK Network moved away from the original philosophy of prescribed common equipment to one of agreed quality procedures for testing which includes the calibration of instrumentation and the test cells, and also data processing and analysis.

The latest developments that have taken place in dynamic testing and analysis driven by the research activities of the PASLINK grouping of outdoor test centres are presented during this workshop and reviews the historical development of the test and analysis procedures currently in use.

Definitions of the physical parameters of interest derived from the energy balance equation:

- UA is the heat transmission coefficient: the heat flow rate in the steady state divided by the temperature difference between the surroundings on each side of the system or component, in W/K. For the 1-D case the U-value, in W/m^2 K.
- gA is the total solar energy transmittance or solar aperture: the heat flow rate leaving the component at the inside surface, under steady state conditions, caused by solar radiation incident at the outside surface, divided by the intensity of incident solar radiation on the component, in m^2. For the 1-D case the g-value [-]

Application of dynamic methods

Over the past decade the interest in renewable energy has increased. Analysis of complex dynamic energy flow systems for ventilation, heating and cooling that contain non-linear processes needs a skill. Considering the built environment, the focus has been mainly on utilising solar energy with promising developments in the integration of photovoltaic (PV) technology in buildings and ventilation, like the solar chimney. Examples include the following.

- External shading devices containing PV cells.
- Roofing tiles, directly replacing traditional pitched-roof materials and also being placed on low-sloped roofs in some climates.
- Ventilated facades where PV is used as the external cladding element. The larger part of the incident solar radiation on the PV elements is converted into sensible heat, which results in a warming-up of the PV elements, which may reduce their electrical efficiency. Ventilating the cavity behind the PV limits the temperature rise, and the warm air may be used for ventilation pre-heat in winter, or driving natural ventilation in summer.
- Dynamic ventilated window systems
- CEN - dynamic methods for in-situ measurement analysis

Apart from energy performance assessment for buildings, dynamic mathematical techniques as have been developed by the Network during several European research projects, can be applied to a wide range of applications; to mention some:

- Integration of Renewable Energies
  - Improved control of energy supply and marketing. Ref [10]
  - Wind and Solar Power Prediction for the grid. Ref [11 and 12]
- Medicines
  - Improving efficiency (Insulin dosing).
  - Pharmaceutical Kinetic and Dynamic Modelling. [see Ref 13]

Testing and Evaluation of buildings and building components.

In order to perform analysis of experimental data with optimal results, the experiment has to be designed to contain the relevant dynamic information of the physical system. Prior knowledge about the characteristic parts of the process is therefore important. In most cases it concerns processes with different time constants (like solar radiation, thermal mass of walls, effects of wind, e.g. convection, etc.). Observations with constant interval are required and should contain at least 5 times the smallest $\boldsymbol{\tau}$ that should be analysed. In general the not measured information is considered as noise by the analysis process.

Analysis is based on the knowledge that the user has of the physical system and that he has translated in a mathematical model. There are different models to express physical systems and to deal with the noise in the available dataseries. Statistical analysis, including correlation and error analysis, is an important part of the whole process.

For obtaining dynamic information from the components a dynamic heating and cooling strategy inside the test cell is needed to ensure that the data obtained from the test contain at least the minimum of information needed to derive the required characteristics. Often an auxiliary resistive heater is used to excite the system and is controlled applying a pseudo randomly ordered on/off sequence [14]. In general, the thermal and solar characteristics of the test specimens are a function of the indoor and outdoor environment conditions, such as temperature level, temperature difference, solar radiation level and position of the sun and sky conditions (clear, overcast). This implies that in case the intention of the test is to obtain results in terms of product information, the characteristics derived from the test may require conversion from actual test conditions to certain standard conditions, such as conditions specified in European standards.

Figure 1. Homogeneous opaque insulated panel and a simple window system placed in the south wall.

System identification techniques have been developed in order to assist researchers in obtaining a better and more accurate knowledge of the thermal characteristics of building components [4]. System identification is the field of modelling dynamic systems from experimental data (see also [15]). A good academic book is given in reference [14] and [16]. A dynamic system has a number of input variables, *u(t)*, it is affected by disturbances *N(t)*, and it has output signals *y(t)*. The general form of a dynamic system is shown in Figure 3.

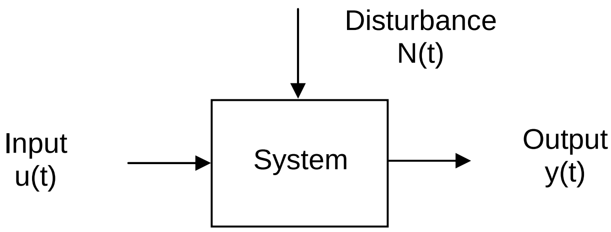

Figure 3. General form of a dynamic system

In brief: system identification is applied by the following procedure:

1. An experiment is performed by exciting the system and regular observing its input and output signals over a specific time interval.
2. These signals are recorded for subsequent “information processing”.
3. A parametric model is developed to process the recorded input and output sequences. Several models can be applied.
4. An appropriate form of the model is determined (typically a linear differential equation of a certain order).
5. A statistically based method is used to estimate the unknown parameters of the model.

Applying system identification techniques on physical systems requires at all stages knowledge of the physical system. For buildings it is important to know what the impact is of cold-bridges, corner effects, etc. The researcher’s goal is to estimate physical parameters by using mathematical models.

The development of dedicated software tools to identify thermal parameters from physical systems has gone hand in hand with the fast development of computing hardware. Software tools like CTSM [17], LORD [18] or the SIT in the MATLAB environment [19] are good examples. AS mentioned before, the application of system identification techniques requires a skill to perform well and therefore the network has organised regular training workshops and System Identification Competitions [20, 21].

1. The Prediction Error Method

PEM (e.g. CTSM, linear models) based on statistical models finds parameters by minimising the error between a k-step (usually k=1) ahead prediction and the measured output. Some characteristics are:

- more sensitive to high frequency parameters

- too optimistic on low frequency (steady state) parameters

- disturbed if residuals are auto correlated

2. The Output Error Method (OEM)

Simulation or Output Error Method (e.g. LORD) based on deterministic models finds parameters by minimising the error between simulation and measurement over a whole test period. Some characteristics are:

- more sensitive to low frequency parameters

- too optimistic confidence intervals if residuals (here simulation errors) are auto correlated

- but due to inertia these are "always" auto correlated

- the application of a correction factor in the minimization algorithm.

Conclusion

In brief it may be said that dynamic methods for analysis require experimental data that contain the dynamic information of the physical system. From the other point of view the conclusion may be made that prior knowledge of the analysis method and the physical system will support a proper design of the experiment. Excite the system based on knowledge of the principle time constants.

The future for Dynamic Methods for Building Energy Assessment

Looking towards the future, one may expect that a number of Directives has been implemented by Member States. Renewable energies, including passive solar, electrical and thermal technologies, will be visible in the built environment more than 10-20 times than we see today. Renewable energy technologies in the built environment are more complex (examples are given in Ref [22 and 23] and more dynamic technologies; the application of dynamic analysis and simulation techniques is therefore evident. Dedicated energy design and evaluation software tools are needed. An integral energy performance assessment is required and industry will develop innovative building products. An in-situ measurement for the thermal performance of buildings under investigation for renovation becomes a common approach. The "near-to-zero-energy-consuming-building" will be developed and requires dynamic tools for design and operation. Here the key-word is storage for both electric as thermal energy, and therefore requires **time** as a part of the process evaluation.

The expertise available in the present DYNASTEE Network can be deployed in particular in the field of dynamic testing, analysis and simulation methods. This is a challenge which the grouping will take by fitting it into the political requirements for building research.

2015

Dynamic mathematical technology is recognised as crucial in optimisation of energy efficiency. Integration of renewable energy technologies in our society is rapidly taking place giving another perspective of the use of available energy resources. The recast of the EPBD, ESD and CPD Directives have taken place and work is ongoing on the update of a 2nd generation of energy standards for calculation methods, certification etc. New buildings consume less energy for space heating while electricity consumption for systems and appliances is increasing.

2020

Ten years from now and a future perspective; in the EU society electric vehicles have become an accepted means of transport in urban areas as well as for long distance. The buildings that are for living and working have become an integral part for distribution and control of energy final consumption. Storage systems are used for peak shaving and valley filling in the energy demand processes. Intelligent metering devices communicate with consumers and utilities and control domestic appliances as well as electric cars.

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