CITIES Webinar, August 12, 2020

**REBUS Connect and Data-Driven Technologies from IEA EBC Annex 71 and on PhD project**

**Christoffer Rasmussen**  
PhD Student, DTU Compute

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REBUS - Renovating Buildings Sustainably  
EBC - Energy in Buildings and Communities Programme  
SMARTTUNE  

CITIES - Centre for IT Intelligent Energy Systems  
Innovation Fund Denmark  

DTU Compute  
Department of Applied Mathematics and Computer Science
BUILDING RELATED ENERGY USE

40 %

TOTAL ENERGY USE IN THE EU

OIL EQUIVALENT

Source: Eurostat
BUILDING RELATED ENERGY USE = 40 %

HOUSEHOLD RELATED ENERGY USE = 25 %

TOTAL ENERGY USE IN THE EU OIL EQUIVALENT

Source: Eurostat
TOTAL ENERGY USE IN THE EU

OIL EQUIVALENT

HOUSEHOLD RELATED SPACE HEATING

16 %

Source: Eurostat
WHOLE HOUSE HEAT LOSS COEFFICIENT (W/K)

PREDICTED

MEASURED

REASONABLE WORLD
WHOLE HOUSE HEAT LOSS COEFFICIENT (W/K)

Source: J. Wingfield et al., 2011
Annex 71: Building energy performance assessment based on in-situ measurements
Semi-parametric modelling of sun position dependent solar gain using B-splines in grey-box models

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\textbf{A B S T R A C T}

Modelling the effects of solar irradiation plays an important role in various applications. This paper describes a semi-parametric (combined grey-box and spline-based), data-driven technique that can be used to model systems in which the solar gain depends on the sun position. The solar gain factor is introduced, i.e. the absorbed fraction of measured solar irradiation, and estimated as a continuous non-parametric function of the sun position. The implementation of the spline-based solar gain factor in a grey-box model framework is described. The method is tested in two case studies—in a model of the internal temperature of a dwelling in Aalborg, Denmark, and a model of the return temperature of a solar collector field in Solrød, Denmark. It is shown that the solar gain factor as a function of sun position is able to account for structural variations in solar gain that may occur due to factors such as shading obstacles and window or absorber orientation. In both test cases, the spline-based solar gain function improved the model accuracy significantly, and largely reduced structural errors in prediction residuals. In addition, the shape of the estimated function provided insight into the dynamics of the system and allowed for a more accurate representation of solar gain effects. 

\textbf{ARTICLE INFO}

\textbf{Keywords:}
Solar gain modelling
Grey-box modelling
Splines
Thermal dynamics
Building energy
Solar heat collectors
A TYPICAL GREY-BOX MODEL

\[
\begin{align*}
\begin{cases}
\frac{dT_i}{dt} &= \frac{1}{C_i} \left( \frac{T_w - T_i}{R_{wi}} + \Phi_{\text{heat}} + g A I_g \right) dt + \sigma_i \, d\omega_i \\
T_i T_w \quad \frac{dT_w}{dt} &= \frac{1}{C_w} \left( \frac{T_i - T_w}{R_{wi}} + \frac{T_a - T_w}{R_{wa}} \right) dt + \sigma_w \, d\omega_w \\
T_i^* &= T_i + \epsilon
\end{cases}
\end{align*}
\]
SOLAR GAIN
THE FRAUNHOFER TWIN HOUSE
Effective window area \( gA \) is calculated as the sum of solar gains from the North, South, East, and West divided by the global solar irradiation \( I_g \):

\[
gA = \frac{\sum \Phi_S}{I_g}
\]
EFFECTIVE WINDOW AREA (gA-value)
ALL CONDITIONS
IF WE CAN ESTIMATE THE EFFECTIVE WINDOW AREA (gA-value)...

\[ gA = \frac{\sum \Phi_S}{I_g} \]

...WE CAN PREDICT THE SOLAR GAIN
EFFECTIVE WINDOW AREA (gA-value)
ALL CONDITIONS

Azimuth angle [°]

gA-value [m²]

0  20  40  60
EFFECTIVE WINDOW AREA (gA-value)

CLOUDY SKY

A constant relation
EFFECTIVE WINDOW AREA (gA-value)

CLEAR SKY

Some kind of non-linear relation
\[ gA = I_d \cdot \theta_d + I_b \cdot (S\theta_b) + \varepsilon \]
\[ gA = I_d \cdot \theta_d + I_b \cdot (S\theta_b) + \varepsilon \]
Method for Scalable and Automatised Thermal Building Performance Documentation and Screening

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Abstract: In Europe, more and more data on building energy use will be collected in the future as a result of the energy performance of buildings directive (EPBD), issued by the European Union. Moreover, both at European level and globally it became evident that the real energy performance of new buildings and the existing building stock needs to be documented better. Such documentation can, for example, be done with data-driven methods based on mathematical and statistical approaches. Even though the methods to extract energy performance characteristics of buildings are numerous, they are of varying reliability and often associated with a significant amount of human labour, making them hard to apply on a large scale. A classical approach to identify certain thermal performance parameters is the energy signature method. In this study, an automatised, nonlinear and smooth approach to the well-known energy signature is proposed, to quantify key thermal building performance parameters. The research specifically aims at describing the linear and nonlinear heat usage dependency on outdoor temperature, wind and solar irradiation. To make the model scalable, we realised it so that it only needs the daily average heat use of buildings, the outdoor temperature, the wind speed and the global solar irradiation. The results of applying the proposed method on heat consumption data from 16 different and randomly selected Danish occupied houses are analysed.

Keywords: thermal building performance; data-driven energy performance documentation and screening; energy signature; occupants effect on heat consumption
Before model extension

Outdoor temperature [°C]

Global irradiation [W/m²]

Sky temperature [°C]

Wind speed [m/s]

Residuals

MODEL: M1

Input

Outdoor temperature

Residual trend

MODEL: M3

Input

Outdoor temperature

Wind speed

Solar irradiation
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<td>151</td>
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<td>2.5 (0.1)*</td>
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<td>72 (13)*</td>
<td>1.2 (0.4)*</td>
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<td>6.9–20.0</td>
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<td>8.9–16.4</td>
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<td>229 (5)*</td>
<td>92 (14)*</td>
<td>4.4 (0.4)*</td>
<td>45 (31)*</td>
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<td>167 (2)*</td>
<td>57 (6)*</td>
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<td>8.1–18.9</td>
<td>1137</td>
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\( H₀ : \)  
\[ U₀ = 0 \quad UA₀ = 0 \quad UA₇ = 0 \quad gA = 0 \quad Φ₀ = 0 \quad T₀ = 17 \]

Significance code ‘*’: p-value < 0.05.
THANK YOU!

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