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Rasooli, Arash

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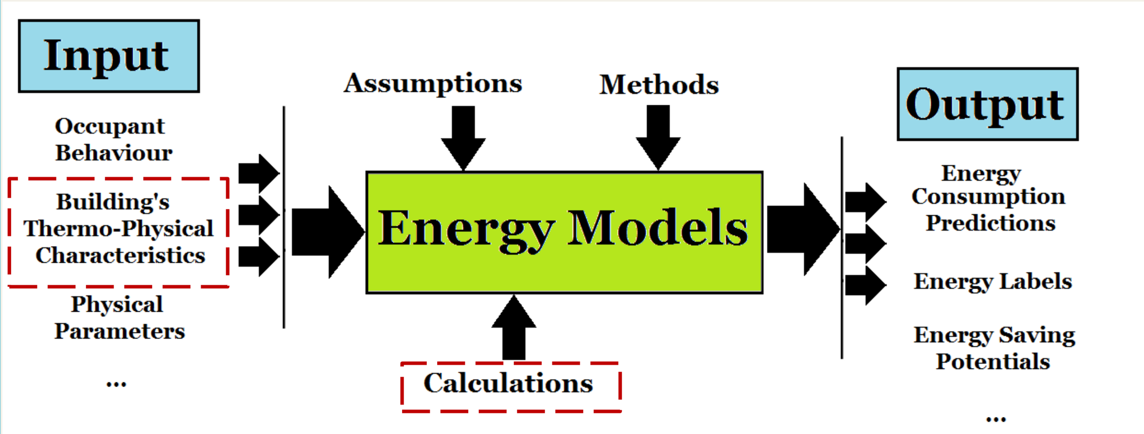
Computational and Experimental Investigation of Walls' Thermal Transmittance in Existing Buildings

Arash Rasooli

Faculty of Mechanical, Maritime, and Materials Engineering
Delft University of Technology, Netherlands

Introduction

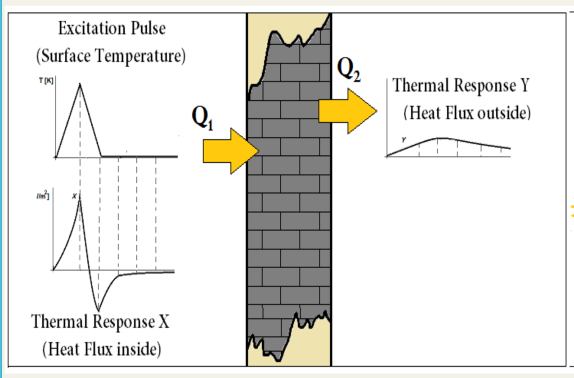
Buildings, accounting for nearly 40% of total energy consumption in Europe, play a key role in energy savings [1]. As a consequence, the definition of building energy labels has become mandatory as a part of EPBD (Energy Performance of Building Directive). In the Netherlands, ISSO publication [2, 3,4], as a part of EPBD, prescribes calculation methods leading to an estimation of the energy consumption in buildings. However, these values have shown to be strongly deviating from the actual consumption [1, 5]. The deviation is higher in buildings with poor energy labels, leading to an overestimation of the energy use for heating by a factor two. This is suspected to relate either to the calculation method, or to inaccurate inputs being fed to it. Majcen et al. [6], performing a sensitivity analysis, showed that the energy models are very sensitive to some of the input data such as U-value of the walls. In the Netherlands, in case of lack of information regarding this variable, which is mostly the case in older buildings, the U-value is not being measured, but suggested based on construction period, conveying a strong possibility of a very poor estimation taking place in such cases.



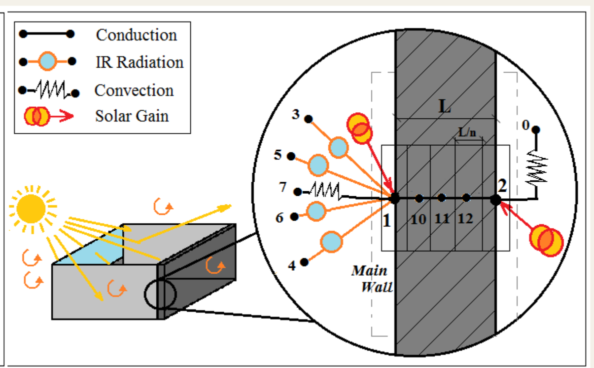
Part 1: Simulations

In the first part of this thesis, simulations are investigated in order to study the possible overestimations caused by the calculation method. Two main aspects are studied:

Dynamic vs Static Simulation

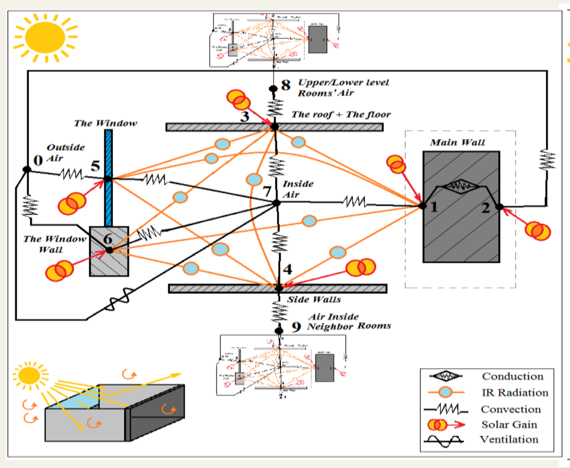


Dynamic Simulation
Response factors Method [8]

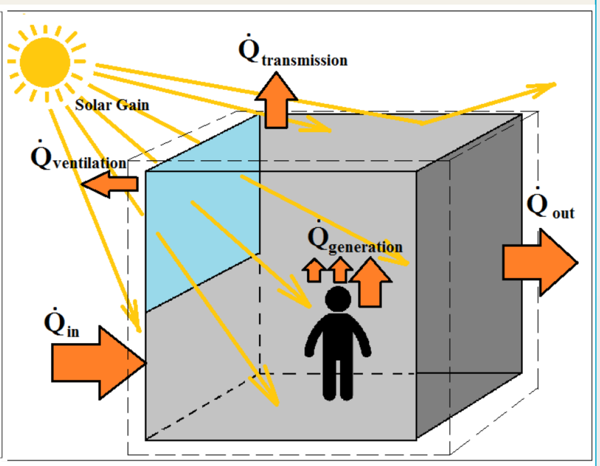


Dynamic Simulation
Finite Difference Method

Detailed vs Simplified Simulation



Detailed Simulation
Thermal Network



Simplified Simulation
Single Control Volume

Results of the Simulations

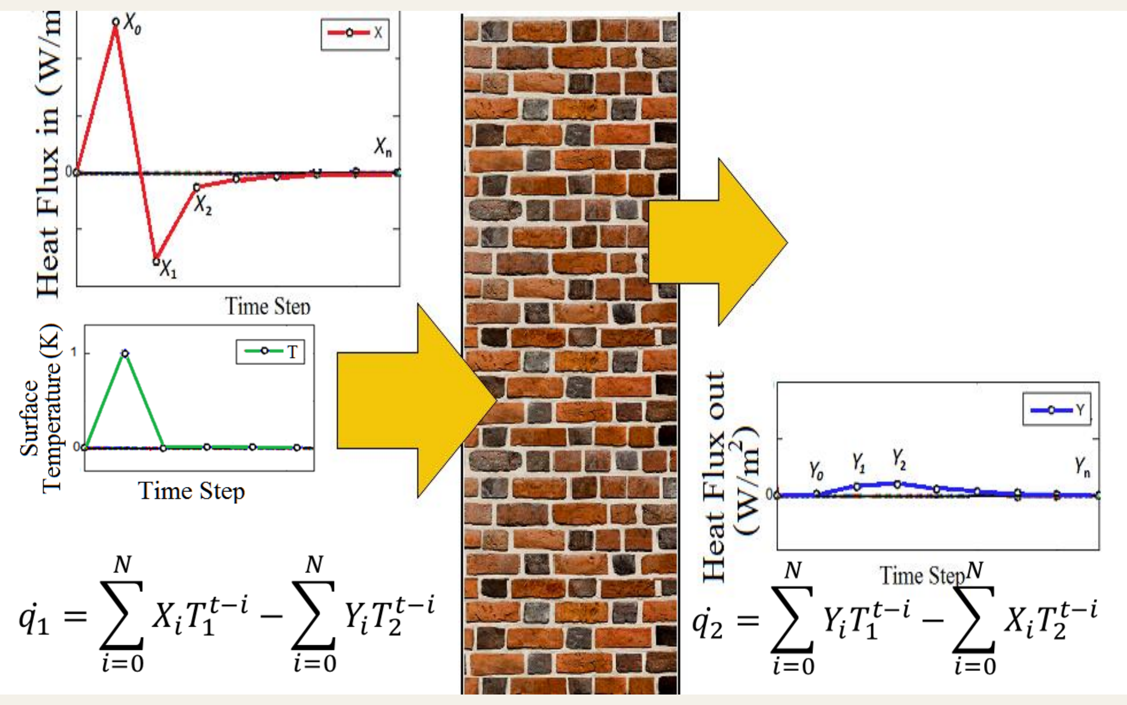
1. The results obtained by the two dynamic methods are identical. It has been shown how different can the effect of heat storage due to the thermal mass be when aggregating from hourly to monthly/yearly calculations.
2. The most obvious simplifications suspected to be causing overestimation of energy consumption include:
   - Determination of heat transfer between adjacent rooms with similar air temperatures
   - Definition of the combined radiative-convective heat transfer coefficients
   - Different definitions of solar gains (by the surfaces or by the air)
   - Including/excluding the solar gains by exterior surfaces

Part 2: Experiments

The most well-known in-situ method for determination of the Rc-value is the one introduced by the international standard ISO 9869 [9] and the American standard ASTM [10], demanding a very long measurement period. Accordingly, there is a need for an in-situ measurement method to aid in determination of the thermal resistance Rc-value of existing walls in a quick, feasible, and cost-efficient, and accurate way. From this part of the thesis, a scientific article is published [7] at the journal of Energy and Buildings.

Excitation Pulse Method EPM

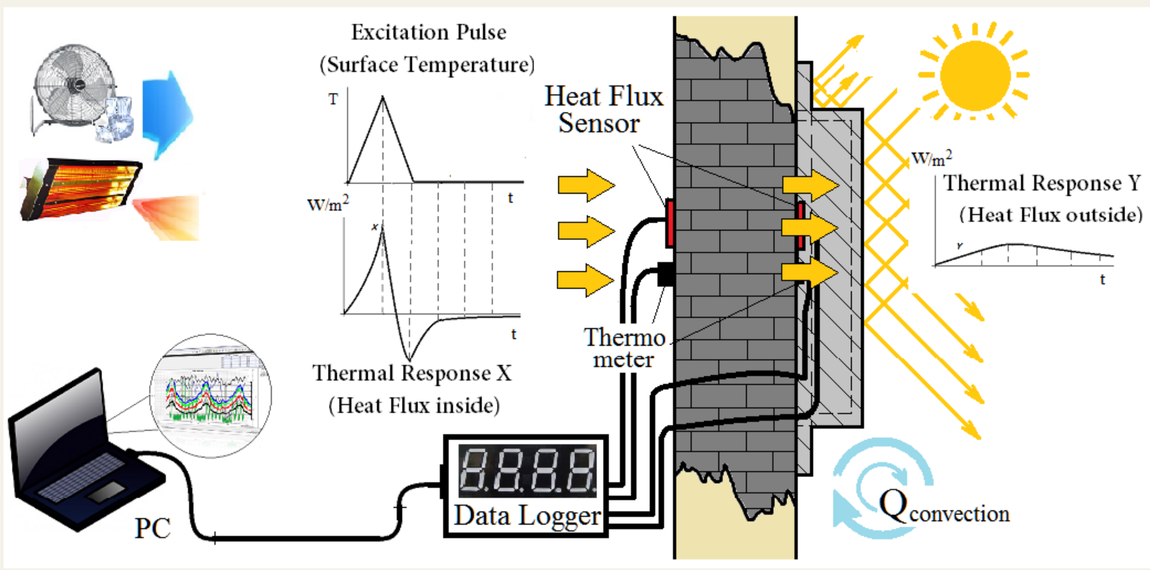
Based on the theory of response factors, a rapid, in-situ, fully transient measurement method is developed at Delft University of Technology, Netherlands, to aid in rapid determination of the Rc-values in existing walls.



Theory of Response Factors: heat flux responses to a triangular surface temperature excitation pulse

EPM

1. The test area of the wall is allocated by an IR camera
2. Two thermocouples and two heat flux meters are mounted on two sides of the wall opposite to each other.
3. Meanwhile, the data from these sensors are gathered, converted, and stored in a data logger unit.
4. An insulating box is mounted on the exterior surface of the wall to avoid the fluctuations
5. Linear heating by an IR heater to a pre-defined triangle's amplitude.
6. Linear cooling by dimming the heater followed by forced convection by fan. After a few time intervals, the test may stop



EPM experimental setup: linear heating followed by linear cooling

The data being processed, it is shown in the thesis that the RFs derived, lead to the equivalent Rc-value of the wall using the following equation:

$$Rc = 2 \times \left(\sum_{i=0}^{n} (X_i + Y_i) \right)^{-1}$$

ISO 9869 Standard Method

EPM tested and validated in three case studies in the Netherlands

In three case studies, EPM has been validated using the Average Method of the standard ISO 9869 [11]:

$$R_c = \sum_{i=1}^{n} \Delta T \Big/ \sum_{i=1}^{n} \dot{q}$$

Results of Experiments

Validation of EPM (2 hours) by ISO 9869 (2 weeks)

Case Study	Test Duration (ISO Standard)	Rc-value: ISO Standard	Rc-value: EPM	Error
1	14 Days	0.17 $m^2K W^{-1}$	0.17 $m^2K W^{-1}$	-0.58 %
2	16 Days	0.77 $m^2K W^{-1}$	0.78 $m^2K W^{-1}$	+1.2 %
3	14 Days	1.57 $m^2K W^{-1}$	1.60 $m^2K W^{-1}$	+2.0 %

The results obtained by EPM show a good agreement with the ones obtained by the standard method ISO 9869 [9]. Accordingly, EPM has been compared to the Rc-values suggested based on construction period (Dutch energy labeling method) to illustrate the possible overestimations.

Rc-value: EPM vs Construction Period

Case Study	Construction Year	Rc-value: Assumed	Rc-value: Measured	Difference
1	1933	0.19 m^2KW^{-1}	0.172 m^2KW^{-1}	+5.6%
2	1964	0.19 m^2KW^{-1}	0.78 m^2KW^{-1}	-76%
3	1680	0.19 m^2KW^{-1}	1.6 m^2KW^{-1}	-88%

U-value: EPM vs Construction Period

Case Study	Energy Label	U-value: Assumed	U-value: Measured	Difference
1	F	2.76 $Wm^{-2}K^{-1}$	2.92 $Wm^{-2}K^{-1}$	-10%
2	E	2.76 $Wm^{-2}K^{-1}$	1.05 $Wm^{-2}K^{-1}$	+163%
3	F	2.76$Wm^{-2}K^{-1}$	0.56 $Wm^{-2}K^{-1}$	+393%

Determination of Rc-values based on construction period can result in up to about 400% overestimation of Thermal Transmittance U-value and therefore the energy demand.

Conclusion

Simulations:

The dynamic simulation of the walls does not change the results of energy demand prediction, as long as they are summed over a long period. However, for the hourly calculations, there is a clear discrepancy between the dynamic and static simulation. The stability of heat flow and temperature fluctuations in dynamic simulations can explain a part of thermal comfort (e.g. wall's radiant temperature) and therefore occupant behavior. Moreover, certain simplifications within the energy labeling calculations are shown to be responsible for a part of the overestimations.

Experiments:

EPM is fully transient, quick, cost-efficient, and reliable. It helps measurement of the Rc-value of a wall within a couple of hours (in contrast with the conventional methods requiring weeks of monitoring). EPM has an accuracy comparable to the existing standard ISO 9869 [9] and therefore, has the potential to be further developed and applied to energy labeling inspections. In case of unknown constructions, it is highly recommended to use EPM as an alternative to the Rc-value suggestions based on construction periods.

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