A MONTHLY METHOD FOR CALCULATING ENERGY PERFORMANCE IN THE CONTEXT OF EUROPEAN BUILDING REGULATIONS

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ABSTRACT

The European Energy Performance in Building Directive (EPBD) requires methods for the calculation of the energy performance for use in the context of building regulations.

The paper describes the rationale behind the development of a simple monthly method for the calculation of the energy needs for heating and cooling of buildings, and positions this method in the field of different possible calculation approaches.

In the light of special requirements in the fields of transparency, robustness and reproducability that are imperative when calculating the energy performance in the context of building regulations (in particular when checking compliance with a legal upper limit to an energy performance level) and in the light of the target audience for this kind of calculations the simple monthly calculation method seems a suitable contender for an EPBD calculation method. First series of validation tests show that the simplified method is well suited to be used in both warm, moderate and cold European climates.

1. INTRODUCTION

European Energy Performance in Building Directive (EPBD)

The European Energy Performance in Building Directive (EPBD, 2002) demands that before the year 2006 all Member States of the European Union implement energy performance (EP) regulations, including minimum EP requirements for all new buildings and EP certificates for all existing buildings when built, sold or rent.

In a short period of roughly one to two years, a whole set of European standards are being developed by the European Committee for Standardisation (CEN) to facilitate the Member States with suitable calculation methods and/or performance criteria for calculation methods. These methods cover building transmission and ventilation heat loss, internal and solar gains, daylighting, heating and cooling demand, heating and cooling system losses, energy consumption for hot water production, ventilation systems and lighting. Evidently they also include renewable energy systems.

The directive explicitly states that the European Commission intends further to develop standards such as EN ISO 13790, also including consideration of air-conditioning systems and lighting. EN ISO 13790 'Calculation of Energy Use for Space Heating' (EN ISO 13790, 2003) is the international standard for the calculation of the energy use for space heating for residential and non-residential buildings. It is the successor of the possibly still better known residential-only EN 832 'Calculation of energy use for heating – Residential buildings'.

In addition, the European Commission has supplied a Mandate (M343, 2004) to CEN to develop a series of standards, each covering a part of the calculation of the energy performance of buildings and procedures for the inspection of heating and airco systems. The latter is due to another EPBD requirement. The result will be a series of standards covering for instance energy needs for heating and cooling, different types of heating and cooling systems, air flow rates, ventilation systems, thermal transmission properties, domestic hot water systems, lighting systems, controls and various types of renewable energy provisions.

According to the Mandate, most of these standards will be published as draft standards for public enquiry (prEN's) during spring 2005, which is a major achievement, knowing that the work on many of these standards started in 2004.

In response to the intention of the Commission expressed in the EPBD, one of the work items (w.i. 14) is aimed at the development of a simple method to calculate the energy needs for cooling, as an addition to the simplified (monthly) method to calculate the energy need for heating in EN ISO 13790:2003. The work on this during the year 2004, under the supervision of CEN TC89 WG4 resulted in a fundamentally upgraded new draft standard. This draft standard has recently been published for Public Enquiry (prEN ISO DIS 13790, 2005).

Calculation methods in the EPBD

The structure of the new prEN ISO DIS 13790 has been prepared in way meant to create **a level playing field** for both simple and detailed methods, by introducing a coherent set of procedures with respect of boundary conditions and assumptions that applies to different types of methods (see figure 1). It maximizes the common use of procedures, conditions and input data, disregarding the type of calculation method. It currently allows for:

- Full description of a monthly (and seasonal) method for cooling, very similar to the method in the current EN ISO 13790:2003 for heating.
- Full description of a simple hourly method for heating and cooling, to facilitate easier introduction of hourly and weekly patterns (e.g. controls, user behaviour).
- The use of dynamic simulation methods, based on procedures that prescribe specific boundary conditions and input data in such a way that these are consistent with the boundary conditions and input data for more simplified types of methods.

The latter is to ensure compatibility and consistency between the different types of methods. The standard provides for instance common rules for the boundary conditions and physical input data irrespective of the chosen calculation approach.

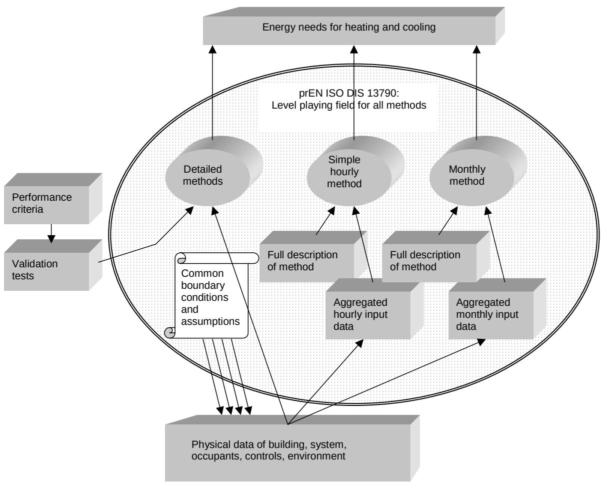

Figure 1: Common rules and assumptions in one set of calculation procedures: level playing field for all methods

Obtaining "a level playing field" is very important for a fair and transparent comparison and legal checking of building energy performance. For instance, this coherent approach prevents that when applying a (validated) detailed calculation procedure thermal bridges are overlooked that are explicitly described in the spelled out procedures for the monthly and simple hourly method; or to prevent that in the calculation of the thermal transmission losses through ground floors the edge losses are not taken into account as is done in the fully described methods.

Example: calculation of thermal transmission heat transfer

The calculation procedure for thermal transmission depends on the type of calculation method, but the assumptions (on environment conditions, user behaviour and controls) and the basic physical data shall be the same for each of the 3 types of calculation methods (monthly, simple hourly and detailed simulation methods). See table 1.

Type of method	**Total heat transfer by transmission**	**Transmission heat transfer coefficients**	**Input data and boundary conditions**
Monthly method	Yes (Q_T)	Yes (H_T)	Yes[1]
Simple hourly method	Not applicable	H_T	Yes[1]
Detailed simulation method	Not applicable	Not applicable	Yes[1]

Table 1: Calculation procedure for thermal transmission heat transfer for the different types of methods

[1]: such as weather data; definition of areas; thermal conductivity and thickness of materials, correction factors for ageing, mounting, moisture; thermal bridges; conditions in adjacent buildings or zones; solar shading assumptions, occupants behaviour with respect to use of solar shading, ventilation, etc.

2. NEED FOR SIMPLIFIED METHODS

For use within the context of building regulations, and in particular for checking compliance with a EP requirement (maximum EP level), there is an urgent need for simplified methods that fullfil a number of basic requirements, as explained further on.

Already within the SAVE ENPER project (2002-2004) extensive discussions were organised between a number of experts, resulting in an overview of advantages and disadvantages of detailed simulation tools versus simplified methods for application within the context of building regulations (van Dijk and Spiekman, 2004).

Role of simplified methods in building regulations

First, in the discussion about the role of simplified methods, there is a tendency to focus on simple input and not bother about simple methods. These two issues should, however, be clearly distincted:

- ***Simplified input*** should be unambiguous (when selecting and when checking), distinguishing (in energy performance), measurable, verifiable and maintainable (to guarantee performance over many years)
- ***Simplified methods*** should combine transparency, reproducibility and robustness with adequate (balanced) accuracy. These qualities are successively introduced in the next paragraphs.

Important requirements

In particular for the application within the context of building regulations, transparency, robustness and reproducibility of a calculation method are important qualities.

- ***Transparency*** means that the method enables the user (and developer) to keep track of each step in the calculation procedure. This is achieved, if the method is clearly described as a set of equations and parameters, limited in size and complexity, with clear rules when and how these shall be applied.

The term transparency may be interpreted as "containing no parameter values with unknown background". Although this should be the ideal situation, it should be sufficient if the *parameters* have a clear physical meaning, with their *values* within a physically understandable range; for instance: a reduction factor, with value between 0 and 1. See the next requirement ("robustness").

- ***Robustness*** means that the method can handle a wide variety of situations, with perhaps loss of accuracy, but without going out of control. This is achieved by the transparency in combination with ensuring that the set of equations have a physical basis, are basically non-dimensional (thus valid from small home to large building), with parameters that are 'intrinsically safe' (for instance the monthly gain utilisation factor going down with increasing heat gains, as introduced further on).
- ***Reproducibility*** means that for a specific case the method leads to the same result, independent of the user. This requires that all options be specified in a concrete and unambiguous way, with no open ends.

Target audience

The ***target audience*** of methods for the calculation of the energy performance for use in the context of building regulations consists of persons or teams who:

- apply the method
- check the result (compliance with building regulations)
- (further) develop and/or evaluate the method (technically and legally)
- implement the method in national/regional building regulations
- supply input data.

The transparency, robustness and reproducibility are of interest for persons applying the method, because the method enables them to understand the method (fast learning curve), protects them against wrong use and provides the insurance that the calculation result will be accepted without discussion.

But also for persons checking calculation results for legal issues, e.g. civil servants checking building permit requests, for whom avoiding ambiguities and disputes is also a major concern.

And, last but not least, also for persons involved in (further) development and/or evaluation of the method and providers of the input data, for whom keeping track of the procedures is essential.

Reproducibility may be most important in case of EP requirements (new buildings and major renovations), because ***in case of strict requirements the economic pressure is high to find and apply the method that gives the best EP value for the lowest investment in energy technologies. This can lead to comparisons between different alternative calculation methods in order to find the best EP value, instead of comparing alternative energy efficient technologies.***

3. MONTHLY METHOD FOR THE CALCULATION OF HEATING AND COOLING DEMANDS

An example of a simple (transparent, robust and reproducable) method is **a monthly method** to calculate the energy needs. The monthly method **for heating** that is used since many years is the method using the concept of the gain utilisation factor (EN 832, 1995; EN ISO 13790, 2003). In The Netherlands this method was, already in the early '90's, extended with a monthly method to calculate the energy demand for **cooling** (NEN 2916, 1995). This method is, as part of the national building regulations that contain maximum integrated EP levels since 1996, since then obligatory for all new non-residential buildings. In the mean time the method or a quite similar method has recently been proposed for adoption in the building regulations in e.g. Belgium (Flanders region) and Germany. Since 2004 the same method applies in The Netherlands also for residential buildings (NEN 5128:2004), mainly to saveguard thermal comfort in summer and to stimulate passive cooling techniques.

However, applicability of the simplified cooling method for other, e.g. Mediterranean and Nordic climates in Europe, has not been demonstrated yet.

The section on validation of the monthly method provides preliminary results on this aspect by subjecting the method to validation tests from Stockholm to Rome (see section on validation). Wherever possible the validation efforts have been based on details, assumptions, input data, calculation factors etc as described in the new prEN ISO DIS 13790 (2005) and using the test cases as currently being drafted under another work item of the Mandate 343 (prEN W.I. 17, 2005).

Accuracy of monthly methods

By the very nature of simplified methods the ***accuracy*** of these calculation methods must be satisfied by applying expert knowledge and expert models when developing and evaluating simplified methods. Here ***balanced accuracy*** is required for all successive steps in the process (the process as e.g. illustrated in figure 2). Balanced accuracy means that the inaccuracies introduced by simplifications at each of these levels must be more or less in balance. Previous experience with montly methods in the Netherlands, Belgium and Germany proves the feasibility of this approach.

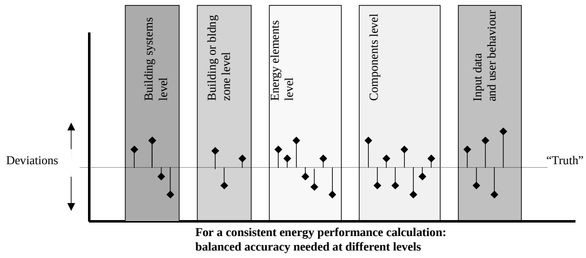

Figure 2 Balance in accuracy needed for the successive steps in the calculation

Basic formula

In the monthly ('quasi-steady state') type of methods, the dynamic effects are taken into account by introducing correlation factors:

For **heating** a utilisation factor for the internal and solar heat sources takes account for the fact that only part of the internal and solar heat sources is utilised to decrease the energy need for heating, the rest leading to an undesired increase of the indoor temperature above the set point. In this approach, the heat balance ignores the non-utilised heat sources, which is counterbalanced by the fact that it ignores at the same time the resulting extra transmission and ventilation heat transfer from the considered space due to the increased indoor temperature above the set point.

The effect of inertia in case of intermittent heating or switch off can be taken into account by introducing a adjustment on the set point temperature or a correction on the calculated heat need.

For each building zone, the energy need for space heating per month is calculated according to:

$$Q_{NH} = Q_{L,H} - \eta_{G,H} \cdot Q_{G,H} \text{ (min.value: } Q_{NH} = 0) \qquad (1)$$

where (for each building zone, per month):

Q_{NH} Is the building energy need for heating, in MJ;

$Q_{L,H}$ is the total heat transfer for the heating mode, in MJ;

$Q_{G,H}$ are the total heat sources for the heating mode, in MJ;

$\eta_{G,H}$ is the dimensionless gain utilisation factor.

The traditional terms ***'losses' and 'gains'*** *have been replaced by the terms* ***'heat transfer'*** *respectively* ***'heat sources'.*** The reason is twofold: a) because in a cooling mode transmission and ventilation losses may become actually gains; b) from physics point of view it is vital to keep a distinction between heat flows that should be modelled as a heat source (like solar radiation, high temperature internal heat sources) and heat flows that should be modelled as a thermal resistance with temperature difference.

Gain utilisation factor

The gain utilisation factor for heating, η_H is a function of the gain/loss ratio, $\gamma_H = Q_{G,H}/Q_{L,H}$, and a numerical parameter, a_H that depends on the time constant of the building (building inertia), τ, according to the following equation (see figure 3):

$$\text{if } \gamma_H \neq 1: \; \eta_{G,H} = \frac{1-\gamma_H^{a_H}}{1-\gamma_H^{a_H+1}} \qquad (2a)$$

$$\text{if } \gamma_H = 1: \; \eta_{G,H} = \frac{a_H}{a_H+1} \qquad (2b)$$

where:

γ_H is the dimensionless gain utilisation factor for heating (= $Q_{G,H}/Q_{L,H}$).

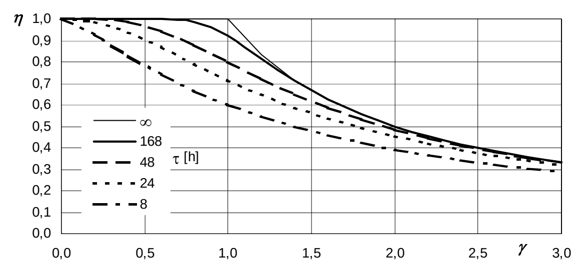

Figure 3. Illustration of the gain utilisation factor for heating

For **cooling** there are two different ways to express the same method:

a) utilisation factor for losses (mirror image of the approach for heating).

b) utilisation factor for gains (similar as for heating).

We will first introduce the **first way** to express the method: A utilisation factor for losses, in casu the transmission and ventilation heat transfer, takes account for the fact that only part of the transmission and ventilation heat transfer is utilised to decrease the cooling needs, the "non-utilised" transmission and ventilation heat transfer occur during periods or moments (e.g. nights) when they have no effect on the cooling needs occurring during other periods or moments (e.g. days).

In this approach, the heat balance ignores the non-utilised transmission and ventilation heat transfer; this is counterbalanced by the fact that it ignores that the cooling set point is not always reached. With this formulation it is explicitly shown how the heat transfer by transmission and/or ventilation attributes to the reduction of the building energy needs for cooling.

For each building zone, the energy need for space cooling per month is calculated according to:

$$Q_{NC} = Q_{G,C} - \eta_{L,C} \cdot Q_{L,C} \text{ (min.value: } Q_{NC} = 0) \quad (3)$$

Where (for each building zone, per month):

Q_{NC} is the building energy need for cooling, in MJ;

$Q_{L,C}$ is the total heat transfer for the cooling mode, in MJ;

$Q_{G,C}$ are the total heat sources for the cooling mode, in MJ;

$\eta_{L,C}$ is the dimensionless utilisation factor for heat losses,.

The utilisation factor for losses is a function of the loss-gain ratio $\lambda_C = Q_{G,C}/Q_{L,C}$ and a numerical parameter, a_C that depends on the time constant of the building (building inertia), τ, according to the following equation. Notice the similarity with the heating mode (mirror image):

if $\lambda_C > 0$ and $\lambda_C \neq 1$: $$\eta_{L,C} = \frac{1-\lambda_C^{a_C}}{1-\lambda_C^{a_C+1}} \quad (4a)$$

if $\lambda_C = 1$: $$\eta_{L,C} = \frac{a_C}{a_C+1} \quad (4b)$$

if $\lambda_C < 0$: $$\eta_{L,C} = 1 \quad (4c)$$

where:

λ_C is the dimensionless loss utilisation factor for cooling (= $Q_{G,C}/Q_{L,C}$).

See figure 4:

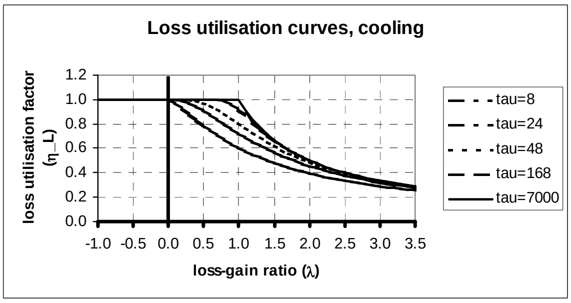

Figure 4. Illustration of the loss utilisation factor for cooling

Note that negative loss-gain ratio values are acceptable, meaning a negative value for the monthly average heat transfer $Q_{L,C}$.

The **second way** to express the method uses a utilisation factor for gains, similar as for heating:

a utilisation factor for the internal and solar heat sources takes account for the fact that only part of the internal and solar heat sources is compensated by thermal heat transfer by transmission and ventilation, assuming a certain maximum indoor temperature. The other ("non-utilised") part leads to cooling needs, to avoid an undesired increase of the indoor temperature above the set point.

In this approach, the heat balance ignores the utilised heat sources, which is counterbalanced by the fact that it ignores all transmission and ventilation heat transfer.

Equation:

$$Q_{NC} = (1 - \eta_{G,C})\, Q_{G,C} \quad (5)$$

with minimum value: $Q_{NC} = 0$.

Where (for each building zone, per month):

Q_{NC} Is the building energy need for cooling, in MJ;

$Q_{L,C}$ is the heat transfer for the cooling mode, in MJ;

$Q_{G,C}$ are the heat sources for the cooling mode, in MJ;

$\eta_{G,C}$ is the dimensionless gain utilisation factor for the cooling mode.

The curves for $\eta_{G,C}$ are in principle the same as for heating (see equation 2 and figure 1), although parameter values dictating the curves may become different due to specific differences between the heating and cooling modes.

Two versions, but in fact identical

Although both ways to express the monthly cooling calculation method were developed independently, it can be proven, by converting equation 2 into equation 4 or vice versa (at least for $Q_L>0$) that both versions are completely identical! For that reason we prefer to speak about two ways to express the (same) method. It can further be derived that, provided that the same input and the same parameter values are used, the following simple conversion can be made:

$$\eta_{G,C} = \lambda_{G,C}\ \eta_{L,C} \tag{6}$$

Without going into a detailed discussion, the first way to present the method has a few advantages:

- Mathematically more robust (e.g. in case of monthly mean negative heat transfer to the environment)
- More direct link to the concept of passive cooling: utilized transmission and ventilation losses

The first advantage may for instance be applicable in extreme warm circumstances, warmer than the warm climate chosen for validation of the method (Rome, see further on).

Intermittent cooling

The effect of inertia in case of intermittent cooling or switch off can be taken into account by introducing an adjustment on the set point temperature or an adjustment on the calculated cooling needs.

4. VALIDATION OF THE MONTHLY METHOD

Validation approach

In parallel with the development of the simplified methods, CEN TC89 WG6 develops validation cases for heating and cooling calculation methods (CEN TC89 W.I. 17, 2005).

With respect to validation in general, we should distinct two fundamentally different tests that lead to different results and should lead to different conclusions:

- **Type A: Diagnostic (or verification) tests**

  The term "diagnostic" is used within IEA. Others use the term "verification". For example, in the CEN test cases mentioned above, the calculation method is not prescribed, but certain parameters, (e.g. fixed surface heat transfer coefficients) are specified. Therefore, the expected tolerances on the test cases have relatively small error bands (and detailed simulation programs may have to be constrained to get within the band). "By definition" a simple (e.g.monthly) method does not fit into this schedule, because it uses an aggregated approach; neither do detailed tools that cannot be forced to follow the strictly defined specifications (see figure 5).

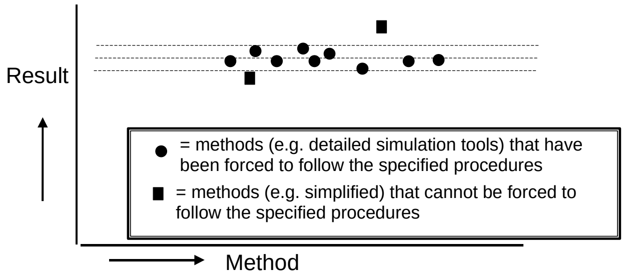

Figure 5. Illustration of a typical result of a diagnostic test

- **Type B: Qualification (or validation) tests**

  The term "qualification" is used within IEA. Others use the term "validation", standing for a comparison of predictions with the real world situation and therefore including many potential sources of error. For the BESTEST qualification tests, programs were allowed more flexibility in modelling assumptions (e.g. surface heat transfer coefficients were not prescribed). In this case the spread of acceptable results is much greater (see figure 6). In this case the monthly method should fit in, because all the methods use their own 'best' approach.

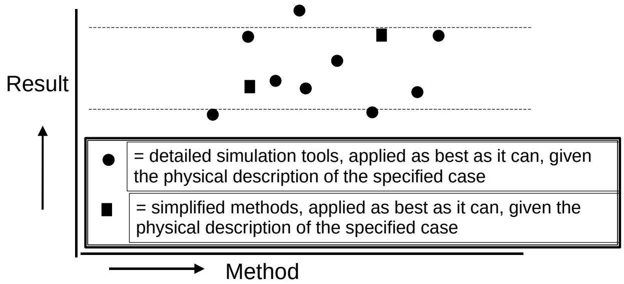

Figure 6. Illustration of a typical result of a qualification test

The validation of the monthly method as described in this section therefore should be of the ***qualification*** type. When subjecting methods to diagnostic (verification) tests a wider margin should be accepted for methods that cannot be (or will not be) forced into the straitjacket of the given detailed specifications. Otherwise a qualification/validation test only should be applied, that shows a realistic spread in the results, disregarding the type of method. A simple method passing a qualification test would be a good candidate for use in the context of building regulations, where the qualities of transparency, robustness and reproducability are the most important.

Preliminary outcomes

Preliminary reference calculation results were available from detailed simulation methods and a simple hourly method (prEN w.i. 17, 2005). Results from the monthly method were compared with data from these reference calculations.

The original set contained only results for one climate (Paris, France). The authors added two more extreme European climates: Stockholm (Sweden) and Rome (Italy). The hourly data for these climates were generated within the projects IEA SHC Task 27 (solar façade components) and EU Swift (Platzer, 2003).

The test cases are typical shoe box cases, with in total 12 variations: continuous and intermittent heating/cooling, heavy and lightweight construction, high and low internal gains; with and without roof.

Results

The following graphs show a summary of the results, organised per climate.

The differences are given as the difference in calculated monthly energy needs for heating respectively cooling, expressed as percentage of the annual energy needs for heating ***plus*** cooling.

It is clear that this may give a too optimistic view in some cases, but otherwise we would need to show all the detailed results in its detailed context. For instance: a relative difference of, say, 30% in energy need for cooling has no real meaning if the absolute level of cooling is negligible compared to the energy need for heating.

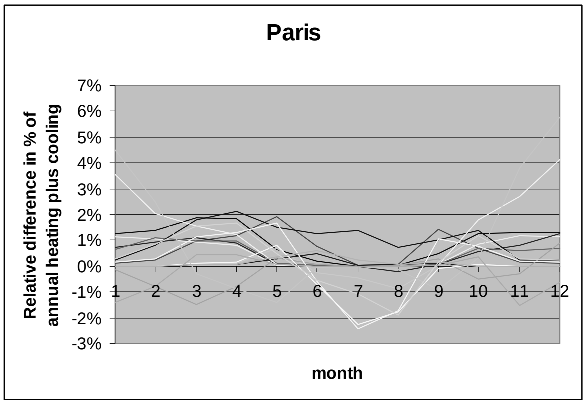

Figure 6 Summary of results for Paris

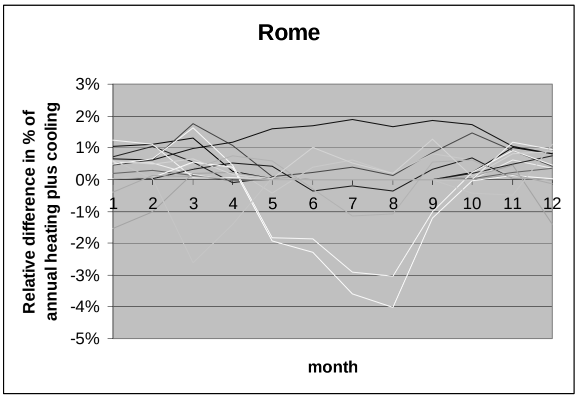

Figure 7 Summary of results for Rome

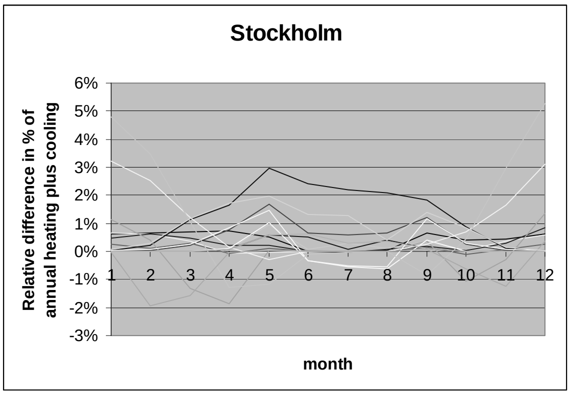

Figure 8 Summary of results for Stockholm

Table 2 shows a summary on the agreement on an annual basis.

Deviation (root mean square for 8 cases)	**Paris**	**Rome**	**Stock-holm**
Heating	10 %	3 %	8 %
Cooling	6 %	8 %	7 %

Table 2: Summary of results on annual basis

The following remarks can be made regarding the outcomes for Paris, Rome and Stockholm:

- Some deviations occur, as expected, in particular near the edges of the heating and cooling seasons.
- Results for cooling (see summer months) are not worse than for heating (see winter months)
- There is no systematic influence of climate.
- Fine–tuning of the method(s), in particular for intermittent heating and cooling is still foreseen and will further decrease the discrepancies.
- One should note difference between diagnostic tests and validation (see next)

As stated in the earlier section of this paper, deviations due to simplifications have to be considered in the context of overall uncertainties and weighted against the introduction of other uncertainties in case of detailed methods.

Validation exercises have shown that the uncertainties that are introduced are within acceptable band width, compared to the other uncertainties, in particular when taking into account the need for these simplified methods in terms of transparency, robustness and reproducability for use in the context of building regulations.

5. CONCLUSIONS AND REMARKS

The European Energy Performance in Building Directive (EPBD) requires methods for the calculation of the energy performance for use in the context of building regulations. A draft of a fully revised version of EN ISO 13790 has been prepared (prEN ISO DIS 13790, 2005) in which a 'level playing field' is created for both simple and detailed methods, by introducing a coherent set of procedures with respect of boundary conditions and assumptions that applies to different types of methods.

The paper describes the rationale behind the development of a simple monthly method for the calculation of the energy needs for heating and cooling of buildings, and positions this method in the field of different possible calculation approaches. The method is based on a monthly calculation method that is already used or prepared for use for calculating energy performance of buildings in the context of building regulations in the Netherlands, Belgium and Germany.

In the light of special requirements in the fields of transparency, robustness and reproducability that are imperative when calculating the energy performance in the context of building regulations (in particular when checking compliance with a legal upper limit to an energy performance level) and in the light of the target audience for this kind of calculations the simple monthly calculation method seems a suitable contender for an EPBD calculation method.

First series of validation tests show that the simplified method is well suited to be used in both warm, moderate and cold European climates. The paper also argues, because of the application in the context of building regulations, inaccuracies have to be regarded from the perspective of "balanced accuracies", which is a wider perspective than simply comparing the results of a simple method against a fully described set of calculation cases.

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