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CEN Standard on
Calculation of non-steady state thermal behaviour of buildings in the warm period

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1. Background

At their October 1988 meeting, the CEN Technical Committee 89 (TC 89) asked Dr. Lorenzo Agnoletto of Padova University (now at Udine University), Italy, to "study the State of the art of procedures adopted in different countries for evaluating internal air temperature during warm season" [1]. The result of this study was a proposal for a European Standard for the calculation of internal temperatures in the warm season as the available methods were found to be either too detailed and difficult to use in practice or unnecessarily compromised the accuracy for simplicity. TC89 approved this proposal and Working Group 6 was set up to carry out its recommendations.

The first meeting of the Working Group took place in September 1989. Referring to Working Group 2 of the International Standards Organisation (ISO) TC163, the case was made for the standard to be presented in the form of a dynamic computer program [1]. The original intention was to produce a computer program as the Standard. This was later modified so that no particular method would be imposed by the Standard. It was, therefore, decided that the Standard text would only contain the main assumptions and allowable simplifications necessary for the calculation of internal temperatures (air, internal surfaces and mean radiant and temperatures). Nevertheless a computer program would be included as an informative annex acting both as an exemplar of the Standard and a reference for validation of nationally developed methods/programs.

A Draft Standard was prepared and finalised, in April 1991, at the Seventh meeting of the Working Group at BRE, Garston. This Draft has since been approved by the TC89 to be submitted for "formal vote" as a European Prestandard (prENV), later this year. This Prestandard is now going through the necessary editing procedure and, after the formal vote by TC89, will be available for use alongside the existing National Standards. After 2 years, the National Standard bodies will be asked to comment on the prENV Standard for a 6 month period. Then TC89 will have to make a decision on the Standard, during last six month period of the life of the prENV. It can decide to either promote the prENV to an EN (European Standard) status, extend the prENV for only one further period of two years, refer it to a Working Group for revision, or abandon it.

BRE has been an active participant in the discussions on technical points. In particular, now that the Standard may lead to the development of different methods or computer programs, BRE insisted on the adoption of an appropriate validation procedure for methods/programs developed on the basis of this Standard.

2. Purpose and Scope

"This European Standard identifies the terms in the heat balance equations and describes the assumptions for a simplified calculation of internal temperatures of a room under transient conditions in the absence of cooling plant" [2]. The Standard identifies the main thermal processes that have a major influence on the performance of a single room under free-floating conditions. The standard also defines the allowable simplifications in modelling these processes and specifies the boundary conditions.

The standard is aimed at the designers (architect/Engineer) who can use the calculation method to evaluate the internal air and surface temperatures in a single zone of their designed building under representative external climate conditions and prescribed conditions in adjacent rooms. The calculated temperatures can then be used in the assessment of thermal comfort (neglecting the air movement and humidity effects) on the basis of local and national criteria. No global European criteria are set for the level of comfort.

This Standard is developed to be used in the development of simplified, user friendly computer programs, to be used as part of the building design process. Programs developed on the basis of this Standard have to be validated according to a procedure given in the Standard.

Although the Standard does not impose a particular solution technique for the heat balance equations, an implicit finite difference solution technique is presented as an informative Annex. This Annex acts both as an exemplar and a reference method to be used in validation procedures for other solution techniques.

Because of simplifications allowed in the method of calculation, the Standard can not be used for calculation of internal temperatures of the rooms (zones) with following characteristics:

- Sunspaces
- Atria
- Indirect passive solar gain designs
- Rooms with large window areas, i.e. when room has a glazing ratio of more than 50% on two or more exposures.

3. Contents of the Standard

The main body of the Standard covers definitions, description of important thermal processes, allowable assumptions in the calculation of internal temperatures and validation procedures for methods developed on basis of the Standard.

The Standard has three normative annexes as follows:

Annex A: External convective heat transfer coefficient
Annex B: Derivation of design climatic data for the warm season
Annex C: Convective heat transfer coefficient for unventilated air cavity

There are also nine informative Annexes to the Standard as follows:

Annex D: An implementation of the Standard - This Annex acts as a reference in the validation procedure.
Annex E: Internal convective heat transfer coefficients - Standard requires that the results of any different method in determining these coefficients should be verified by this annex.
Annex F: External long-wave radiant heat transfer coefficients
Annex G: Internal long-wave radiant heat exchange - Standard requires that the results of any different method in determining these coefficients should be verified by this annex.
Annex L: Shaded area of a plane surface due to external obstructions - Standard requires that the results of any different method in determining these coefficients should be verified by this annex.
Annex M: Internal gains
Annex N: Ventilation and Infiltration
Annex P: References

4. Calculation method

The method refers to a room (a single zone) with known conditions for the adjacent spaces. Energy balance equations for each component of the room, namely, enclosure elements (walls, roofs, ceilings, windows and doors) and the internal air are set up and solved for the unknown air and surface temperatures. The main thermal processes and allowable assumptions in setting up these heat balance equations are described in the main body of the Standard and its Annexes as described above. Here a brief description of the main assumptions and procedures is given.

4.1 Main assumptions

These are the assumptions that have to be made to model a real world object or its interaction with other objects into a mathematical model. For each homogeneous (and discretized) element (and/or layer of an element) of the room (including the air spaces and layers) the heat balance equations are written considering the heat exchanges due to conduction, convection, mass transfer, short-wave, long-wave radiation interchange and heat injection from heat sources (occupants, lights and appliances). Non-homogeneous materials are treated as homogeneous but with an equivalent conductivity derived from their thickness divided by their total resistance.

The main assumptions in setting up the heat balance equations for the room and its components are as follows:

- Room air has a uniform temperature.
- Surfaces of the room enclosure elements are assumed isothermal.
- Thermo-physical properties of the fabric material are time and temperature independent.
- Heat conduction through opaque and transparent enclosure elements is one dimensional.
- Convective heat transfer coefficient at internal surfaces are only dependent on the direction of heat flow.
- Air spaces are treated as air layers bounded by two parallel surfaces which are perpendicular to the direction of heat flow.
- Convective heat transfer coefficients for unventilated air layers depend on the direction of heat flow only.
- Convective heat transfer coefficients for ventilated air layers depend on the air movement velocity and the direction of heat flow only.
- Long-wave radiation exchange at the external surfaces is assumed to take place between the surface and the surroundings that have a temperature equivalent to the ambient air temperature. Also the long-wave exchange coefficients are assumed to be constant (time and temperature independent). Long-wave exchange with the sky is also taken into account at the sky temperature.
- Room air and air layers are transparent to long-wave radiation. Long-wave interchange can be linearised using time and temperature independent coefficients.
- Optical properties of transparent materials are time and temperature independent.
- Transmitted short-wave radiation is assumed to be of diffuse nature.
- Distribution of transmitted solar radiation to internal room surfaces is time independent.
- Shading of the diffuse component of the solar radiation is not considered.
- Heat storage in transparent materials is neglected.
- Heat conduction through transparent materials is neglected.
- Blinds/shutters and curtains are treated as extra transparent layers with specified optical properties and treated in the same way as transparent materials.
- Dimensions of the enclosure elements are taken as internal.
- Heat transfer by convection is related to the air temperature at a large distance from the surface.

4.2 Climate Data
One of the main uses of the Standard would be to answer the design question of whether a building needs air-conditioning or not. The climate data has a major effect on the results of the calculation and consequently on the design decision. Because of this the Standard imposes the climate data selection and gives a method for this selection in Annex C. The goals is to select a weather data that is representative of the local climate and can be meaningfully used as a basis for the assessment of overheating in buildings. Such climate data should neither represent an average summer day nor the hottest possible days ever but a hot period that has a given chance of occurrence.

Several methods and criteria for chances of occurrence are being investigated by WG6. The final decision is awaiting the newly formed WG9 of TC89. One of the candidate methods is as follows:

This method requires that climate data for statistically meaningful number of years will be analysed for the location in question. These data are then analysed on the basis of air temperature as follows:

- For each month from June to September, inclusive, the hottest 4 day spells are identified for each year of available climate data.
- 50% of these 4 day spells are rejected on basis of having lower mean daily average temperatures.
- Another 50% of the remaining 4 day spells are rejected on basis of their higher daily swing temperature (maximum - minimum).

The above gives a return period of once every four years of the hottest 4 day spells.

- Hourly averages of the remaining 4 day spells is used as the design climate data.

A second method under consideration uses a similar principle but rejects only 50% of the dataset and selects a 4 day spell for which the difference between the mean daily temperature for the consecutive days has an ascending slope. This method has a return period of once every two years of hot spells that make the highest contribution to overheating.

In finite difference methods, need arises for start up temperature for all nodes to be known. For this purpose the Standard suggests that the calculations are first carried out using mean monthly data and repeated until the predicted internal air temperature does not change more than 0.01 °C for two consecutive calculations.

4.3 Input requirements
Data are needed on geometry, construction, window type, shading devices and internal gain of the room. Geometrical data is mainly area of surfaces and their orientation. Slope of walls is assumed to be always vertical and ceiling and floors horizontal. Window geometry is needed in more detail, location, width and length as the dimensions and location of shading devices are needed. Constructions are assumed to be multi-layered and data on their material's properties as well as surface characteristics are needed.

Judging by the method of calculation and nature of equations used it can be concluded that a detailed information about the building and its internal gains is required. This implies that the standard is to be used at a late stage of the design.

4.4 Output of the method
No specific requirement is set for the output data. However, the Standard implies that the output should include the internal air dry bulb temperature, internal surfaces' temperature, mean radiant temperature and dry resultant temperature, their maximum and their time of occurrence.

4.5 Reference Method
An informative annex, Annex D, gives the details of the reference method. The method is based on the solution of simultaneous differential equations, representing the heat balance equation for each node, using the implicit technique. This technique has the advantage of being stable independent of the time step selected.

In addition to the main assumption allowed by the Standard, the reference method makes some further simplifications as follows:

- Walton method [4] for internal long-wave exchange is used. This method assume that all surfaces exchange heat, by means of long-wave radiation, with an imaginary point which has some average characteristics derived from all surfaces.

- All internal heat gains are assumed to be of convective nature.

- A fixed distribution is assumed for the transmitted solar radiation.

The method has been tested against analytical solutions for some of the main thermal processes and results found to be in good agreement. Comparative validation techniques, based on BRE/SERC [5] and IEA tests [6], are also being proposed for further validation of the method against more detailed calculated methods.

4.6 Validation Procedure
The Standard specifies that any method which is different, in any way, from the one given in Annex D will have to comply with some specified tests. These tests are part of the main body of the Standard and are therefore mandatory.

The validation tests are of two categories. A set of tests are devised for testing single processes/algorithms, namely conduction process, internal long-wave heat exchange and shading algorithms. Another set of tests deal with many of these algorithms interacting simultaneously, the so called "whole method validation". In the whole method validation two single room buildings, with different geometries and window sizes, are specified and a number of tests specified. The tests are designed to give indications on the treatment of the main algorithms for different construction and window types.

The results of the test using a method, different from that devised in Annex D, have to agree, within a specified accuracy, with those of the reference method. The reference methods results and the qualifying differences for each test are given in the Standard.

5. Development of a simplified method
After adopting the draft Standard as an prENV, the TC89 has asked the WG6 to prepare a Standard for a simplified method which can be used as a first step in evaluation process and probably at earlier stages of the design. Such a simplified method may also be used by people with limited expertise and with limited information about the building and may not involve the use of computers.
WG6 is considering this request and is likely to propose an existing simplified method which will be compatible with the present Prestandard by the end of the 1992.

6. Cooling load calculations
Working Group 6 has also been asked to develop, in collaboration with two other Working Groups, a Draft Standard for the calculation of cooling load and the required energy in buildings. The intention of WG6 is to use the methods developed and adopted for the present prENV as a basis for the cooling load calculations.

7. Implications for Industry
The national status and the enforcing mechanism of the Standard, during and after its experimental life will be covered elsewhere [7]. Here, only a comparison is made with the existing methods used in the UK. Since there are no formal standards on the subject, an experimental European Standard has the potential to be used more widely.

The main use of the Standard depends on the local climate as well as the building regulations and standards in force. In the UK, it is envisaged that the main uses of the method will be that of:

- assessing whether a building needs air-conditioning or not and
- assessing the risk of overheating in designs incorporating passive solar features.

In some countries, like Switzerland, regulations are being prepared which specifies that designers have to justify their decision for installing air-conditioning systems in buildings. The increasing attention and awareness on global warming and green issues, in particular within the EC, is likely to lead to more widespread adoption of such regulations in Europe.

The Standard, in principle, can replace the present de-facto standard in the UK, i.e. the CIBSE method of calculating internal temperatures [8]. However, as mentioned in Section 3.3, the method requires detailed input data on the construction and the shape of the building under study. Because of this more simplified methods, such as the CIBSE method which allow the use of globalised parameters, such as U-value and Admittance, will still have to be used at earlier stages of the design.

A similar situation exists for the cooling load calculation Standard that is being prepared by the Working Group 6 of TC89.

Because of the potential impact of the Standard on the design of buildings in the future, Industry needs to pay close attention to the developments of the Standard and take part in the National commenting exercise.

8. References

[1] Agnoletto L., Minutes of the first meeting, Sept. 1989
[2] Agnoletto L., Seventh Draft of the Standard dated December 1991.
[3] Agnoletto L., Report to November Meeting of CEN TC89., Sep 1989.
[4] Walton G.N., A new algorithm for radiant interchange in room loads calculations", ASHRAE Transactions Vol. 68 Part 2, 1980
[5] Bloomfield D.P., An investigation into analytical and empirical techniques for dynamic thermal models of buildings, BRE/SERC Collaboration, 1988
[6] Bloomfield D.P. and Jiang Y., A program documentation and the work of IEA Annex 21, Proceedings of systems simulation in Buildings Conference, Belgium, University of Liege, 1990
[7] The Seminar's morning session, Talks by T. Field of DOE and A. Pinney of BRE
[8] CIBSE, CIBSE Guide Volume A, Section A8, CIBSE, London , 1986