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Modelling of double ventilated façades according to the CEN Standard 13790 method and detailed simulation

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ABSTRACT

The European Energy Performance of Buildings Directive (EPBD) encourages the use of technologies in buildings that can potentially improve their energy performance. Double ventilated façades can often have a positive contribution to this objective and their effect has to be quantified during the calculation of the overall energy performance of the buildings. The updated EN ISO 13790 Standard is part of the new set of CEN Standards that have to be delivered to support the EPBD requirement for a general framework for the methodology of calculation of the total energy performance of buildings. It contains a method to calculate the contribution of the double ventilated façades to the annual heating and cooling requirements of buildings. At the same time (validated) detailed simulation tools, which are also allowed in this Standard, offer an alternative way to quantify the effect of the double ventilated façades on the buildings' energy performance. This paper examines a case study where the ESP-r simulation program and the method described in the Standard were used for a common building specification to investigate the impacts from a double ventilated façade on the energy performance of the building. It discusses the potential differences that might appear when a detailed simulation tool (ESP-r) is used with constrained (according to the Standard) inputs and also unconstrained inputs, compared to the outputs obtained from the method described in the Standard. Some parametric studies are included to show whether the same trends are obtained using both the method in the Standard and the detailed simulation approach.

1. INTRODUCTION

Double ventilated façades have been increasingly used nowadays as a means to increase thermal and visual comfort in buildings while reducing their energy consumption (Poirazis, 2004). This is especially important for highly glazed buildings where the aesthetic considerations required by the architect should be maintained without compromising the energy performance of the building. A number of types of double ventilated façades exist and have been classified in the literature (Loncour et al., 2004) depending on the type of ventilation within the façade (natural, mechanical and hybrid), the partitioning of the façade's cavity (partitioned by storey, multi-storey, etc.) and the ventilation strategy with regard to the way the air is circulating within the cavity (outdoor air curtain, indoor air curtain, etc.).

The use of technologies or techniques for improving the buildings' energy performance, such as the potential use of double ventilated façades, are now encouraged with the introduction of the Energy Performance of Buildings Directive (EU, 2003). One of the Directive's requirements is that Member States should establish a common methodology at national or regional level for the calculation of the integrated energy performance of buildings based on all the areas specified in its Annex. However, this implies that an appropriate and accurate quantification of the effect that the double ventilated façade will have on the energy performance of the building should also be considered.

In an effort to implement the requirement for the calculation of the integrated energy performance of buildings, a set of European and international Standards were prepared or updated in order to suggest methods and provide the required material for the calculation. One of the main Standards in this set is the updated prEN ISO DIS 13790 (2007) which provides a framework for the calculation of energy use for space heating and cooling in buildings, mainly for annual periods. This Standard contains a method to calculate the contribution of specific types of double ventilated façades to the annual heating and cooling requirements of buildings. This method is used for the simplified methods that are fully prescribed in the 13790 Standard while on the other hand the use of (validated) dynamic simulation tools is also allowed as an alternative method to be used for the objectives of the Standard. This paper focuses on the practical application of the simplified monthly quasi-steady state method that is described in the 13790 Standard and on the option of using a detailed simulation program, such as the ESP-r program (ESP-r, 2007), for a common building specification that includes a double ventilated façade. It should be mentioned here that this study does not aim to follow any validation procedures and does not intend to prove the accuracy of any of these methods. The intention is to investigate the use of these methods in a practical case and to highlight the potential dangers from the selection of a wrong method by building professionals when evaluating the performance of double ventilated façades.

2. METHODOLOGY

A case study for a building that includes a double ventilated façade was defined and a calculation of the annual energy needs for heating and cooling was performed with both the simplified monthly 13790 method and the ESP-r simulation program when common procedures for the inputs and boundary conditions were followed according to the Standard's instructions. The systems used to cover these energy needs were not considered in the calculations (i.e. their efficiency, parasitic losses, etc.). For a better evaluation of the results, it was considered important to ensure equivalency for the inputs and the boundary conditions used in both methods.

2.1 Case study and parametric analysis

The case study is a 3-storey building with a total floor area of 144 m^2. The external walls have a U-value of 0.245 W/m^2K and are of low thermal mass. The calculations for the base case were done for a northern/central European location (based on weather data for Amsterdam). The double ventilated façade was initially considered to fully cover the South façade from the bottom to the top of the building without any separation between storeys. The double ventilated façade consists of a double glazed clear inside layer and a single glazed clear outside layer. The application of the method described in the 13790 Standard is limited to double ventilated façades with an air cavity width between 15 mm and 100 mm. For this reason, the analysis was done for a 100 mm wide double ventilated façade. The way to determine the air flow rates within the façade in the case of a natural ventilation strategy was not clear in the 13790 Standard method and for this reason a mechanical ventilation strategy was studied in this paper. In the cases where the annual heating energy requirements are studied, the air intake is the bottom outside layer of the double façade. It then flows through the cavity of the facade with the help of the mechanical ventilation system and at the top of the building is evenly distributed in the three storeys. For annual cooling energy assessments and the base case, a similar configuration for the double façade is studied but this time the air at the top of the double ventilated façade exits back to the outside environment. To avoid increasing the complexity of the calculations with regard to the simplified monthly method, all spaces were assumed to have the same set-points for heating and cooling and also the same heating, cooling, ventilation and internal gains schedules. If this assumption was not made then a multi-zone calculation, possibly with thermal coupling between the zones, would have been necessary for the simplified monthly method to maintain equivalency with the detailed simulation program. This would have significantly complicated the calculations involved in the simplified monthly method and would have required a large amount of input data for its application.

The parametric studies presented in this paper were conducted for the following cases:

- A case where the air enters from outside the base of the double facade and is evenly distributed in the internal spaces when it reaches the top of the façade (base case for heating) and another case where the air enters from the base of the double facade and exits to the outside from the top of the double facade (base case for cooling). The base case is also studied without the double ventilated façade. In the latter two cases, the air flow in the spaces is provided separately from the outside air (without preheat).
- Three different ventilation rates. The base case (0.75 air changes/hour), a case with half the base case's ventilation rate (0.375 air changes/hour) and a case with twice the base case's ventilation rate (1.5 air changes/hour).
- Three different building orientations. The base case was rotated 90^{o} and 180^{o} anticlockwise. In these cases, the double façade was facing east and north respectively.
- Three different internal heat gains schedules. The base case incorporates an hourly varied occupants and lighting schedule where the gains from occupants and lighting during the occupied hours are 12 W/m^2 and 10 W/m^2 respectively. During unoccupied hours and during the weekends, these values are ten times smaller than those for the weekday occupied periods. One of the other two cases uses higher internal heat gain values compared to the base case but with the same hourly patterns and similarly, the last case uses lower internal heat gain values than the base case, again with the same hourly patterns.
- Three building locations and climates based on Southern, Central and Northern European weather data.
- Four different heating and cooling strategies. The base case has a steady operative temperature setpoint during the year and for the other three cases, different intermittent heating or cooling strategies were used.

2.2 Equivalency between the simplified method and detailed simulation program

An accurate evaluation of the results and their sensitivity to the design changes is only possible when the two methods use the same inputs and boundary conditions.

The same climate data in terms of ambient temperature and solar radiation were used for both methods. Incident solar radiation data for all the building surfaces were extracted from ESP-r's output and were used as an input for the monthly 13790 method.

The setpoint temperatures in all cases, including the cases with intermittent heating or cooling, were the same for both methods. In ESP-r, ideal controls were used for maintaining the operative temperature in the zones to be the same as those used for the simplified monthly method. In the cases of intermittency, the method described in the 13790 Standard for the simplified monthly method was used to determine the relevant reduction factors.

To ensure equivalency for the issues with regard to the heat transfer by transmission and the internal heat capacity of the building surfaces, the same areas, materials, layers and constructions of the building were used in both methods. Consequently, the thickness and the conductivity of every surface layer were ensured to be the same. In order to set the same surface resistances for the inside and outside face of the surfaces, the pre-defined values in prEN ISO DIS 6946 (2006), and prEN ISO DIS 10077-1 (2006) in the case of windows, have to be used. This means that for ESP-r the inside and outside convective and radiative heat transfer coefficients must be set to fixed values through the calculation period which is not normal practice. For the heat transmission to the ground, the method described in Annex D of the prEN ISO DIS 13370 (2006) was used to model with ESP-r the construction of the floor and the boundary conditions below it. This included a specific thickness of soil and an underlying virtual layer (with specific thermophysical properties). The resulting calculated monthly ground temperatures were used over the simulation period. Thermal bridges were not included in either of the methods. For the foundation, a slab on the ground was assumed with 1-D thermal conduction only.

Regarding the ventilation or infiltration heat losses, the same air flow schedules were used on an hourly and monthly basis during the calculation period. However, ventilation heat losses or gains are based on the operative temperature in the simplified monthly method and on the air temperature in ESP-r.

The same internal heat gains schedules were also used for both methods (i.e. the hourly schedules in ESP-r were converted to monthly schedules for the simplified monthly method). In ESP-r, 50% convective and 50% radiative internal heat gains were assumed in accordance with the ISO 13790 instructions.

Finally, for the inputs with regard to the solar heat gains, the same surface properties (e.g. absorptivity of the external opaque walls) and optical data were used in ESP-r and the simplified monthly method. Climate data, as previously mentioned, were the same as were external view factors to the ground. The longwave radiation heat exchange between the building surfaces and the sky was not included in the calculation in any of the two calculation methods (to allow a fixed external surface resistance to be used).

3. RESULTS AND DISCUSSION

The results obtained from the two calculation methods for the annual heating and annual cooling energy requirements are shown in Table 1 and Table 2 respectively.

3.1 Annual heating energy requirements

In general, apart from the intermittent heating cases, the results produced from ESP-r for the heating energy are lower than those produced from the simplified monthly method. For the base case, ESP-r's predicted annual heating energy requirements was 21.1% lower than the simplified monthly method's result (61.8 kWh/m^2 for ESP-r and 78.3 kWh/m^2 for the monthly method).

Table 1: Annual heating energy requirements (kWh/m^2)

	Monthly 13790	ESP-r
Base Case – air enters the spaces from the top (Amsterdam – 19 ^{o}C setpoint)	78.3	61.8
Base Case without double ventilated façade	103.4	75.1
Base Case – air exits from the outside upper layer of the double façade	83.6	74.6
High ventilation rates (1.5 ac/h in the building spaces)	119.5	103.5
Low ventilation rates (0.375 ac/h in the building spaces)	59.3	41.3
Rotate 90^o anticlockwise (double façade is facing east)	93.3	82.5
Rotate 180^o anticlockwise (double façade is facing north)	91.3	80.7
High internal heat gains	63.6	39.5
Low internal heat gains	87.7	76.4
Climate Aberdeen	94.7	74.9
Climate Athens	14.9	4.1
Intermittent heating 7-17.00h	23.3	29.2
Intermittent heating 0-10.00h	23.3	42.1
Intermittent heating (different periods during the day at 19 ^{o}C)	11.7	25.9

Table 2: Annual cooling energy requirements (kWh/m^2)

	Monthly 13790	ESP-r
Base Case - air exits to the outside from the top (Amsterdam – 24 ^{o}C setpoint)	108.7	63.8
Base Case without double ventilated façade	122.1	91.0
Base Case – air enters the spaces from the top of the double façade	115.1	77.1
High ventilation rates (1.5 ac/h in the building spaces)	96.1	45.3
Low ventilation rates (0.375 ac/h in the building spaces)	117.9	77.6
Rotate 90^o anticlockwise (double façade is facing east)	84.3	45.6
Rotate 180^o anticlockwise (double façade is facing north)	81.5	36.2
High internal heat gains	157.4	103.0
Low internal heat gains	87.7	47.5
Climate Aberdeen	86.9	37.8
Climate Athens	259.6	227.0
Intermittent cooling 7-17.00h	78.1	52.6
Intermittent cooling 0-10.00h	78.1	18.4
Intermittent cooling (different periods during the day at 24 ^{o}C)	78.1	42.6

Both methods highlighted the potential energy savings that the double ventilated façade could offer in terms of heating requirements when the base case was studied without the double ventilated façade. In this case, the results between the two methods varied by 27.4% with respect to the monthly method's result (75.1 kWh/m^2 for ESP-r and 103.4 kWh/m^2 for the monthly method). A better agreement between the results of the two methods was noticed in the case where the air in the façade is not distributed in the building spaces but exits from the outside upper layer of the double façade. ESP-r predicted 74.6 kWh/m^2 while the monthly method predicted 83.6 kWh/m^2, a 10.8% difference with respect to the monthly method's result. However, the result of ESP-r in this case does not differ a lot from the previous case where the building was studied without the double façade (74.6 kWh/m^2 and 75.1 kWh/m^2 respectively), while the difference for these two cases in the results of the monthly method were large (83.6 kWh/m^2 and 103.4 kWh/m^2 respectively). This is probably because the ventilated façade was modelled as an additional thermal zone in ESP-r and the conditions of the air inside it varied over the year resulting in variations in the heat losses of the adjacent building spaces. In the monthly method, the double façade was only treated as an extra construction layer with an air layer that had a fixed thermal resistance.

Differences between the results of the two methods were also noticed for the cases where different ventilation rates were studied, especially for the case of the lower ventilation rates where the results of the two methods varied by 30.4% with respect to the monthly method's result (41.3 kWh/m^2 for ESP-r and 59.3 kWh/m^2 for the monthly method).

For the cases where two alternative building orientations were studied, both methods confirmed that orientating the building in a way that the double façade faces south would offer more energy savings in terms of heating requirements. Differences though in the results of ESP-r and the monthly method were also noticed in these two cases.

Similarly, differences between the outputs of the two methods were noticed in the rest of the results presented in Table 1. The most significant differences were produced in the case where high internal heat gains schedules were used, the case where south European climate data were studied and some of the intermittent heating cases.

3.2 Annual cooling energy requirements

The positive effect of the double ventilated facade in terms of energy savings for cooling purposes can also be noticed from the results of Table 2. However, ESP-r predicted that the double façade has a larger impact on the cooling energy requirements (29.9% improvement: from 91 kWh/m^2 to 63.8 kWh/m^2) than that predicted by the monthly method (11% improvement: from 122.1 kWh/m^2 to 108.7 kWh/m^2).

For all the cooling cases, the results between the two calculation methods differ on a larger scale than of those obtained for the heating cases. These differences often exceeded 50% with respect to the monthly method's result. For example, for the case where the building is orientated such that the double façade faces north, the monthly method predicted 81.5 kWh/m^2 while ESP-r predicted 36.2 kWh/m^2, which is 55.6% lower than the monthly method's result. An exception where a better agreement between the predictions of the two methods was achieved is the case that the building was studied using south European climate data. In this case, the result of ESP-r (227 kWh/m^2) is 12.6% lower than the monthly method's result (259.6 kWh/m^2).

4. CONCLUSIONS

The simplified monthly method described in the 13790 Standard and the ESP-r detailed simulation program were applied to a common building specification that incorporates a double ventilated façade. Equivalency between the inputs and the boundary conditions used in both methods was ensured according to the 13790 instructions. For the specific case study, both methods highlighted the benefits with regards to energy savings in terms of heating and cooling requirements with the use of a double ventilated façade. However, in most cases significant disagreements were noticed between the results obtained from the two methods, both in terms of the absolute values and in the trends observed in parametric analyses. This was especially the case for cooling energy requirements calculations. An exception was the case where cooling energy requirement calculations were performed for a south European climate.

The application of double ventilated facades often incorporates cost implications and any potential energy benefits that this would offer will usually require to be accurately estimated. This also became important with the introduction of EPBD and its requirement for an integrated energy performance calculation of buildings. This study cannot be used for determining the accuracy of any of the calculation methods that were used in this paper. While the application of these methods in practice is not simple, the selection criteria for their use should be based on their validation history and the confidence that they provide to the users concerning their accuracy. Clearly, more work is required to determine the validity of both simplified and detailed methods for modelling double facades.

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