Status and recommendations for better implementation of ventilative cooling into Danish standards, building legislation and energy compliance tool

Christoffer Plesner [*1] and Michal Pomianowski[2]

1 Velux A/S
Ådalsvej 99
2970 Hørsholm, Denmark
**Corresponding author:*
christoffer.plesner@velux.com

2 Aalborg University
Thomas Manns Vej 23
9220 Aalborg, Denmark

ABSTRACT

Ventilative cooling (VC) is an application (distribution in time and space) of air flow rates to reduce cooling loads in spaces using outside air driven by natural, mechanical or hybrid ventilation strategies. Ventilative cooling reduces overheating in both existing and new buildings - being both a sustainable and energy efficient solution to improve indoor thermal comfort. In new buildings VC, may save cooling energy and thereby make it easier to fulfil future energy legislation for buildings. VC is an important topic supported by the International Energy Agency (IEA) - where the IEA Annex 62 has had a special focus on this area.

Low energy buildings are highly insulated and airtight and therefore subject to overheating risks, where VC might be a relevant solution. One of the tasks of IEA Annex 62 has been to evaluate the current status and make recommendations for better implementation of VC in future standards, legislation and compliance tools for 11 different countries, incl. e.g. Denmark, Italy and Japan.

The purpose of this paper is to evaluate how well ventilative cooling is currently integrated into Danish national standards, legislation and compliance tools and thereby make future recommendations based on this.

The approach is to evaluate to which extent certain ventilative cooling parameters are integrated into Danish standards, legislation and compliance tools through questionnaires asking if e.g. cross ventilation is included, which calculation time step is used for thermal comfort and if the position of windows is taken into account.

Based on the answers from the questionnaire a concise status was established for Denmark, conclusions were drawn and thereafter concrete recommendations were given.

The Authors hope that the recommendations found throughout the IEA Annex 62 activities will help and inspire policy makers, regulators and experts to improve future standards, legislations and compliance tools and better address natural ventilative cooling.

Results show that ventilative cooling is not explicitly addressed in Danish building legislation nor national standards. There is presently, among others, lack of information on how to use windows, night cooling possibilities, window control and automation. In Danish building legislation and compliance tool, design air flows are specified by the designer as fixed air flow rates split up into winter and summer operation. In reality air flow rates, especially from natural ventilation, are seldom or never constant and a recommendation could be to allow the possibility for variable air flow rates. The recommendation for better implementation of ventilative cooling in Danish standards could be to have more “design specific” standards providing guidance on how to achieve well-functioning ventilative cooling systems reducing overheating in buildings. The concrete recommendations should give inspiration to regulators when making future revisions of standards, legislation and compliance tools.

KEYWORDS

Ventilative cooling, standards, legislation, compliance tools, recommendations

1 INTRODUCTION

Ventilative cooling (VC) can be described as the effective use of outside air by means of natural, mechanical, or hybrid ventilation strategies to reduce or eliminate the need for compressed cooling. VC is not a product and should be rather regarded as an integrated part of the design strategy. Case studies demonstrated that the use of VC, in many situations, can result in considerable energy savings as well for new constructed buildings (Tranholm, 2012) as for renovation or retrofit situations (Flourentzou, 2012).

In spite of the considerable energy saving potential of VC, architects and engineers are sceptical to apply VC in their building design. One of the major reasons is the uncertainties regarding the estimation of energy performance and thermal comfort in buildings in which VC is applied. A possible key incentive to increase the opportunities for VC, and lower the uncertainties for building designers, are regulatory measures. (State-of-the-art-review, Kolokotroni et al., 2015) state that further research should be conducted to study if the VC potential can be estimated using monthly time steps. Monthly average models are the most used in European compliance tools and could underestimate the cooling potential of VC and therefore, reduce the application for building designers. On the other hand, it seems relevant to start considering incorporation of dynamic, hourly-based models in the building regulations. These models increase the possibilities to evaluate and optimize VC and thereby increase its application potential.

The overall objective of this article is to describe the current status and future recommendations for better implementation of ventilative cooling in standards, legislation and compliance tools in Denmark. The work is targeted building designers, builders and experts working with building energy performance standards, legislations and compliance tools with the goal of helping these target groups with concrete recommendations, for better future implementation of ventilative cooling, using this report as background information on how ventilative cooling is implemented, and what can be done to improve the implementation. The aim is that building designers, builders and experts, will be sufficiently informed of the missing aspects of ventilative cooling found in existing standards, legislations and compliance tools in Denmark and thereby act on these findings to ensure better buildings in future with reduced overheating issues.
The work behind this article is a part of the subtask A: “Recommendations for standards and legislation” of the research of IEA Annex 62 on “Ventilative Cooling” which ran 4 years from 2014-2017 that operates under International Energy Agency (IEA). For this task, the information needed is obtained by questionnaires answered by experts in 11 countries, all of which participate in IEA Annex 62. Though as mentioned this article only contains the findings from Denmark, though also some general conclusions from the main work are also drawn for better overall understanding.

In this article, the current status for the integration of ventilative cooling in standards, legislation and compliance tools in Denmark are presented in section 2. Thereafter the recommendations for better implementation of ventilative cooling are given in section 3 and finally a conclusion is drawn at the end of the article in section 4.

2 STATUS OF VENTILATIVE COOLING IN DANISH STANDARDS, LEGISLATION AND COMPLIANCE TOOLS

The split of roles and responsibilities between standards, legislation, and compliance tools differ from country to country. The collective task is to set up targets for certain parameters and methods to evaluate if these targets have been met. The targets are assumed to be defined in the legislation and the methods to evaluate if the targets are met are defined in standards and/or national compliance tools.

The aim of this section is to give a status of how ventilative cooling is implemented in Danish standards, legislation and compliance tools. For more detailed information on the answers given for Denmark please see the filled in questionnaire in Table 1 in

APPENDIX A.

2.1 Status of ventilative cooling in Danish standards

Overall there are very few Danish national standards concerning ventilative cooling. Actually, only one has been evaluated, (DS 447:2013) dealing with requirements for ventilation systems in buildings. This standard has a very useful overview of requirements and what to include when designing and dimensioning ventilation systems, hereunder natural ventilation systems using passive techniques for e.g. ventilative cooling. In (DS 447:2013) both natural, mechanical and hybrid ventilation systems are defined, as well as demand controlled ventilation and summer comfort (e.g. ventilative cooling) is described.

In Denmark, (DS 447:2013) is commonly applied in practice when making ventilation systems, instead of CEN EN and ISO standards, which is why (DS 447:2013) is the only reviewed national standard in this article.

Due to the length of this article the evaluation of CEN EN standards, CEN Technical reports and ISO standards are not part of this article, but narrowed down to only national inputs.

2.2 Status of ventilative cooling in Danish legislation

The type of legislation differs from to country to country, as not all countries have e.g. regional legislations. Different countries depending on their geographical size, authorities, structures, etc., might have both national or national and regional legislations. In Denmark, there is only national building legislation and no regional legislations. The fact that in Denmark there is only national legislation can be explained by the relatively uniform climate of the entire country, not large in geographical size, uniform building traditions and not large population.
Several countries, among them Denmark, have taken steps to integrate ventilative cooling into their building legislation, which is considered as a positive development.

Ventilative cooling is not explicitly addressed in Danish Building Regulations. Minimum required ventilation air flow rates are defined for hygienic purposes (indoor air quality) and not for thermal comfort. Thermal indoor comfort criteria with respect to number of overheating hours are specifically addressed for residential buildings and less specific for other building types but this criterion is presently not directly linked to any technology solution, for example, ventilative cooling.

In Denmark, thermal comfort criteria are mandatory for residential buildings. For residences, it should be proved by simplified (but still hourly) calculations that the temperature does not exceed 27°C for more than 100 hours and 28°C for more than 25 hours (Danish BR 18, 2018). For other buildings than residential, the building owner sets the maximum number of hours the temperature can exceed 26°C and 27°C". Often design guideline (DS 474, 2017) is used that states that temperatures above 26°C should not be exceeded for more than 100 hours and that temperatures above 27°C should not be exceeded for more than 25 hours during a typical year. Moreover, (DS 447:2013) states that indoor temperature should not exceed 26°C (unless it can be excused by special processes in the kitchen). However, how these criteria should be achieved are not specified although for residential buildings it is written that, if the building has openable windows that allow airing of the space, then it should be possible to obtain these criteria. However, how to use the windows, night cooling possibilities, window control and automation is not mentioned.

Other key statements can be found in (Danish BR 18, 2018) and supplementing it, in guideline document (Danish SBi Anvisning 213, 2016) that refer to ventilative cooling are:

- Air flow rates should be reduced when the need for ventilation is reduced.
- In rooms with strongly variable loads it should be possible to adjust air flow rates to the needs.
- Air recirculation is **not considered** as an alternative to heat recovery.
- Building Regulation for ventilation systems specifically refer to (DS 447:2013) - this means that both natural and mechanical ventilation systems are considered as ventilation possibilities.
- Danish Building Regulation define specifically indoor thermal comfort criteria for residential buildings and less specific for other buildings. For residential buildings, Danish legislation permits simplified calculation method to document that criteria are held, see also “Summer comfort” calculation in chapter about the "status of ventilative cooling in Danish compliance tools". This method is not explicitly referred to in Building Regulation text but in fact it is the method that was recently incorporated into Danish compliance tool, namely “Summer Comfort” calculation.

Thermal comfort calculation method for other than residential buildings require dynamic tools that is able to take the Danish Design Reference Year weather data set into account. **Other criteria, such as validation agreement, are not stated** and thermal comfort calculations are not performed by compliance tool.

2.3 Status of ventilative cooling in Danish compliance tool

Since 2015, the Danish Building Institute - SBi, has implemented an additional feature to the official compliance tool to evaluate thermal comfort. This module is called “Summer comfort” and is used to evaluate the thermal comfort in summer in residential buildings through hourly calculations (described as total number of hours above 27°C and 28°C). It should be highlighted that for many years the same compliance tool primarily served as documentation of energy performance which is still based on monthly calculations.
It is essential that national compliance tools can interpret the legislation in a fair and correct manner in order for ventilative cooling to become fully considered as a mean of ventilation and cooling and at the same time respected as an influential technology on energy use and indoor climate. The degree of complexity among national compliance tools can vary and it is sometimes difficult to distinguish between national legislation and national compliance tools, but the compliance tool should reflect what is stated in the national legislation.

Due to the limited number of parameters available in the compliance tool, only some features of ventilative cooling can be considered. For example, the Danish compliance tool allows to promote cross-ventilation, number of openable windows and take the geometrical free area of windows into account. However, this approach is still limited for modeling ventilative cooling properly and therefore more advanced calculation tools should be considered and connected to the existing compliance tool, without jeopardizing well-known approaches.

As stated in (State-of-the-art-review, Kolokotroni et al., 2015) “Most countries have as their default a monthly energy calculation, which is not well suited for ventilative cooling. More complex calculations are generally possible in the energy performance calculations, but you need to be an expert and the complex calculations are time-consuming”. Denmark is one of these countries with its obligatory energy compliance tool Be18 (earlier versions are Be6, Be10 and Be15) that performs monthly energy calculation and that since 2015 allows for simplified thermal comfort calculation (Summer comfort), but only for residential buildings.

As indicated in (Belleri, 2014) “Danish building legislation allows in general terms to take into account the effect of ventilative cooling, but does not specify how. Be18, the Danish compliance tool, allows users to input a ventilation rate value for ventilative cooling, but does not assist them in determining the value. It also does not take into account thermal comfort improvements due to elevated air velocity”

In the Danish compliance tool, ventilation air flow rates are defined as constant air flow rates. Moreover, in Danish compliance calculation, ventilation air can be specified as natural or mechanical. From the energy point of view this is positive because energy savings due to heat recovery (mechanical) and savings on operation of the fan (natural) can be considered in the overall energy performance of the building.

Moreover, the air flow rate can be varied from summer to winter season and between day and night. Therefore, although the air flow rate is given as a constant value, the tool is to some extent able to capture the dynamic character of the ventilation performance. Selection between single-sided and cross ventilation strategy is not possible directly through the software interface, but recommended air flow rates take into account these strategies recommending higher air flows for cross ventilation than single-sided ventilation. Also, a simple relation between air flow rate and openable window area is included in the help file of the tool (not in the interface).

For the energy compliance check, the Danish compliance tool performs 12 (steady-state) monthly calculations. This simplification is the primary reason why the compliance tool is not able to capture the dynamic character of the ventilative cooling performance with an adequate resolution.

Thermal comfort compliance calculation (only for residential buildings) should be performed for the selected critical room with the highest risk of overheating. The critical room is selected by the designer. Moreover, the calculation is hourly and based on a simplified energy balance method that takes solar heat gains into account through the windows located in the critical room. Solar heat gains are taken into account for window area, window orientation, properties for solar gains and are specific for the calculated building. **Other loads are not included**. Design air flows are specified by the designer as fixed air change rates separately for winter and for summer with distinction between day and night for the summer case. In case of the building being naturally ventilated, air flow calculation is estimated taking into account the ratio between the effective window area and floor area. If the building is mechanically ventilated then maximum designed air flow rate should be applied both for day and night operation. **The calculation algorithm behind the method is however, not explained**. The outcome is provided as number of hours above 27°C and 28°C. **In practice, this calculation**

would often be the only one that documents indoor thermal comfort in new residential buildings.

3 RECOMMENDATIONS TO VENTILATIVE COOLING IN DANISH STANDARDS, LEGISLATION AND COMPLIANCE TOOLS

The aim of this section is to give recommendations to better implementation of ventilative cooling in Danish standards, legislation and compliance tools.

It is recommended that the full effects of ventilative cooling are evaluated reflecting the real conditions for the building, control, use and climate. This should in particular include the actual building physics and geometry. Legislation should include or refer to guidelines, standards or compliance tools on how to calculate the cooling effect, resulting temperatures and the energy performance. Moreover, compliance tools should also reflect what is stated in the legislation.

3.1 Recommendations to ventilative cooling in standards

Overall the most important Danish national standard that has been evaluated in this report concerning ventilative cooling is (DS 447:2013). This standard deal with requirements for ventilation systems in buildings and has a very good and useful overview of requirements and what to include when designing ventilation systems, hereunder natural ventilation systems using passive techniques.

A recommendation could be to have a more "design specific" national standard on ventilative cooling, actually showing guidance on how to achieve well-functioning ventilative cooling systems, e.g. looking at the integration of ventilation components for natural ventilation/ventilative cooling like in (CIBSE AM 10:2005), instead of focusing on the concrete requirements. This issue should be further investigated in future national standards, and furthermore the work of (DS 447:2013) could be used as inspiration in the new projects starting up in CEN and ISO.

To allow for ventilative cooling to be better addressed in standards both at the design stage, where initial calculations of e.g. the natural forces are made as well as, at more detailed stages where more detailed calculations are needed, it is important that several parameters are taken into account, such as:

- Assessment of overheating, e.g.:
  - Thermal comfort indicators, including adaptive temperature sensation
  - Energy performance indicators
- Acknowledgement of natural and mechanical ventilative cooling
- Acknowledgement of night cooling
- The support of calculation methods that fairly treat natural ventilative cooling for determination of air flow rates including e.g. the dynamics of varying ventilation and the effects of location, area and control of openings

3.2 Recommendations to ventilative cooling in legislation

The recommendations for national legislation in Denmark with regards to ventilative cooling are listed below:

- Ventilative cooling should be explicitly addressed in Danish legislation (presently it is not)
- Cooling capabilities of natural and mechanical ventilation systems should be directly indicated.
- Thermal comfort criteria with respect to overheating in other buildings than residential, for example, offices, schools, day-care institutions are still up to the investor. For these buildings applies, as well, thermal comfort criteria for working spaces. If reading these criteria carefully one would notice that they are not explicitly defined. Furthermore, thermal comfort criteria recommended by the Danish Working Environment Service and the ones from standards are not exactly identical. **Therefore, thermal comfort criteria in other buildings should be set in order.**
- Legislation text should be more specific with regards to ventilation strategies in order to cool/maintain acceptable thermal comfort.
- Natural ventilation strategies: single-sided, cross- and stack-ventilation should be clearly identified with respect to realistic ventilation capacities, application, other regulations such as fire regulations.
- Proof risks and limitations with regards to operation and capacities of natural ventilation should be explicitly stated. Proofs should consider: burglary, insects, rain, safety, noise and pollutions.

3.3 Recommendations to ventilative cooling in compliance tools

To allow for ventilative cooling to be treated in compliance tools evaluations, several parameters should be considered, such as:

1. Assessment of overheating, e.g.:
    a. Thermal comfort indicators, including adaptive temperature sensation
    b. Energy performance indicators like e.g. virtual cooling needs, cooling consumptions etc.
2. Assessment of increased air flows when efficient ventilative cooling systems are used:
    a. Differentiation should be made i.e. for cross- or stack ventilation vs. single-sided ventilation, automated systems vs. manual control, large vs. small opening areas (roughly included in Denmark, though many countries do not even take this point into account, so it is important to mention)
    b. Associated airflows should preferably be based on building physics for e.g. dynamic tools (using pressure equations) or – as a simpler solution - on "coefficients" which increase air flows based on the chosen system.

Although the Danish national compliance tool reflects some flexibility to describe ventilative cooling, there is still place for improvement.

The recommendations for national compliance tool in Denmark for future updates with regards to ventilative cooling are listed below:

- Possibility for variable air flow rates, ventilation time schedules and simple control strategies should be the first one to be implemented for the ventilation strategy description (assuming that calculation is hourly and not monthly). Presently compliance tool calculations do not allow grasping the required dynamic response of the ventilation to the varying loads in legislation.

- Key performance indicators, such as Cooling Requirements Reduction (CRR) and Ventilative Cooling Seasonal Energy Efficiency Ratio (SEER) should be included in compliance tool calculations.
- Calculation algorithm behind the "Summer comfort" module in BE18 should be elaborated and explained in the tool help file.
- There is differentiation between day and night air flows and summer and winter season air flows but still they are used as average values for very long time spans. More discretized time step for ventilation description should be used.
- At present, real dynamic characteristics of ventilation and air based cooling capacities are not included in the compliance tool calculations, both for mechanical and natural ventilation. Therefore, compliance tool results should rather be used as tools to compare one building with other building performance, but not to draw conclusions on real building performance.
- Air flows in natural ventilation system are specified disregarding window position in the building, specific opening geometry and characteristics and airflow paths to other openings. Therefore, the compliance tool should at its present stage of development not be used as design tool (which often is done). Presently, aside airflow calculations are required to gain trust in natural ventilation performance and to use "more correct" average air flows in compliance tool calculations.
- Proofs constrains for automated controlled windows should be specifically addressed because they would have great influence on building comfort and energy performance.
- Two complementary means could be used to introduce ventilative cooling into Danish compliance tool(s)
  - Using ventilative cooling to reduce "virtual" cooling needs of the evaluated building, regardless of any cooling system installation.
  - Using ventilative cooling to reduce overheating hours, meaning that room temperatures should be evaluated accurately.

4 CONCLUSION

Generally, ventilative cooling is not very well included in standards, legislation and compliance tools across the evaluated countries and the level of detail for evaluation of ventilative cooling, ranges vastly from simplified to detailed methods, e.g. from pure monthly average models to more dynamic hourly-based models.

When revising standards, legislation and compliance tools with respect to calculation and design of ventilative cooling systems, it should be ensured that the text is technology neutral, thereby not favouring specific technologies and allowing emerging technologies such as hybrid systems.

In difference to most European compliance tools, using the monthly average models that could underestimate the cooling potential of ventilative cooling, there has in Denmark been made an improvement. This improvement is the implementation to the official compliance tool of a "Summer comfort" module that performs hourly calculations of thermal comfort in summer in residential buildings only. This method could be seen as an "intermediary" approach, in between the mentioned very simplified monthly average models and the more dynamic hourly-based models. Although the method is a step forward, it is equally important that the calculated or allowed air change rates are high enough to actually achieve the needed cooling effect. Here improvements in the Danish method are still needed – by e.g. ensuring the associated airflows are preferably based on building physics for e.g. dynamic tools (using pressure equations).

Even though the benefits of ventilative cooling are widely acknowledged, its use by e.g. designers or architects strongly depend on a few intertwined challenges:

- The adequate modelling of natural ventilation and especially of air flows
- The share of the energy for cooling for summer comfort and overheating risk is to become equivalent to energy consumption for heating in winter
- To adequately predict the expected "thermal comfort and cooling requirements", as well as the "energy performance" when using ventilative cooling in buildings (this could e.g. be based on Static models (e.g. Fanger PMV model) or Adaptive models (e.g. adaptive comfort model))

5 ACKNOWLEDGEMENTS

Acknowledgements go out to the IEA EBC Annex 62 "Ventilative cooling" participants

6 REFERENCES

Tranholm, G. T., Roth, J. K. (2012). Reducing energy consumption in an existing shopping centre using natural ventilation. *AIVC*

Flourentzou, F., Irwin, D., Stasis, T. (2012). Hybrid ventilation and cooling technics for the new Nicosia Townhall. *AIVC- 2nd TightVent*

Kolokotroni, M., Heiselberg, P. (2015). *Ventilative Cooling - State Of The Art Review.* EBC Programme - Annex 62 Ventilative Cooling

DS 447:2013 (2013). Ventilation in buildings – Mechanical, natural and hybrid ventilation systems. Danish standard

BR18 (2018). Danish Building Regulation

DS 474:1993 (2017). Danish code for Thermal Indoor Climate

A. Belleri. (2014). Integrated design methods for natural ventilation, PhD thesis

SBi Anvisning 213 (2016). Bygningers energibehov, Danish SBi guideline

CIBSE AM 10:2005 (Application manual, UK). "Natural Ventilation in Non-Domestic Buildings", 2005

7 APPENDIX A

Parameters	Danish standard for NV, MV & HV; DS 447:2013		Danish legislation, BR15		Compliance tool Be18	
	Residential	Non-residential	Residential	Non-residential	Residential	Non-residential
Single-sided ventilation	Yes	Yes	No	No	Not specific but there is link between anticipated air flow and effective window area.	Not specific but there is link between anticipated air flow and effective window area.
Cross ventilation	Yes	Yes	No	No	Not specific but there is link between anticipated air flow and effective window area.	Not specific but there is link between anticipated air flow and effective window area.
Stack ventilation	Yes	Yes	No	No	No	No
Night cooling	Yes	Yes	No	No	Yes, separate air flow can be specified.	Yes, separate air flow can be specified.
Free cooling	Yes	Yes	No	No	Yes, by natural ventilation, then no fan energy consumption.	Yes, by natural ventilation, then no fan energy consumption.
Hybrid systems	Yes	Yes	No	No	Yes, natural and mechanical system can be specified in one building.	Yes, natural and mechanical system can be specified in one building.
Position of windows in building	Yes	Yes	No	No	No	No
Is wind included in your calculation?	Yes [11]	Yes [12]	No	No	No	No
Effect of having manual or automatic window operation	Yes	Yes	No	No	Yes, automatic control would increase anticipated air flow.	Yes, automatic control would increase anticipated air flow.
Steady-state or dynamic calculation?	Steady state and dynamic calculation [11]	Steady state and dynamic calculation [12]	*Thermal comfort may be documented by simplified dynamic calculation.	*Thermal comfort to be documented by dynamic calculation.	Simplified hourly calculation	Thermal comfort: Not included in compliance tool.
				** Energy performance is documented through steady-state calculation	Energy: Steady-state	Energy: Steady-state monthly
Time-step (monthly or hourly)?	Monthly and hourly [11]	Monthly and hourly [12]	Comfort: hourly calculation	Comfort: hourly calculation	Comfort:hourly	Monthly
			Energy performance: monthly calculation	Energy performance: monthly	Energy performance: monthly calculation	
Indicate important issue not included in this table			Question if legislation directly address Ventilative Cooling or cooling by means of air. For Danish case the answer would be No	Question if legislation directly address Ventilative Cooling or cooling by means of air. For Danish case the answer would be No		Thermal comfort: Not included in compliance tool. Overheating hours are recalculated to Watts and add as punishement for energy performance

Table 1 - Ventilative cooling parameters in standards, legislation and compliance tools in residential buildings and non-residential buildings in Denmark