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Efficiency Examination on the Kampmann Door Air Curtain System ProtecTor

Expert Report based on Laboratory Testing and CFD Computational Calculations

Prof. Dr.-Ing. Bernd Boiting
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1. Objective

The aim of the research and calculations described here is to evaluate the ProtecTor Air Curtain System made by Kampmann in comparison to conventional air curtains.

The assessment is based on measurement data from previous tests carried out in the Kampmann R & D Center and additional CFD simulation calculations.

The examination shall first determine whether the investigated systems have a fundamental function for thermal shielding. To that, the basics shall be descripted on which a correct assessment is to be made. Only the basic principles shall be presented. Therefore, if the detailed planning process is of interest, reference is made to the variety of theoretical work at Münster University of Applied Sciences as well as to the Dutch ISSO publicatie 110 Luchtgordijnen,

An efficiency assessment shall not be based on a comparison between unprotected and protected door openings. For this, sufficient investigations have already been made to show that air curtain systems are fundamentally suitable means when door openings must be constantly open even in unfavourable weather conditions.

Rather, air curtain systems shall be assessed comparatively. The focus is on single air stream (standard) and dual air stream systems. A dual air stream system for example is used by the ProtecTor system of Kampmann which is examined here. The objective of this report is to determine the part of the heat output of the air curtain systems, which is not supplied to the heating of the room but is released into the environment as a loss.

2. Door Air Curtain Systems

2.1 Basis for a Correct Design of Door Air Curtain Systems

Door air curtains are used to partition areas of internal space from the outside environment if they are to be made permanently accessible via large external openings, or in industrial areas if areas with different temperatures are to be efficiently separated despite permanently open connection doors.

Since these systems have a high energy requirement despite the high potential for savings, correct planning and operation is the prerequisite for an efficient operation. The devices must be optimally designed regarding their discharge velocities, air volume flows and supply air temperatures.

Scientific studies have shown that the air outlet form of a air curtain decides less on the achievable shielding effect, than the achievable leaving air velocity.

Many theoretical studies carried out at Münster University of Applied Sciences confirm the connection between the change in momentum of a deflected air curtain and the pressure force on an opening caused by wind and by temperature differences:

$$\Delta p \cdot A_{Door} = \rho \cdot A_{Curtain} \cdot c^2$$

Formula 1: Total air pressure at the door opening, as well as counter pressure by the air curtain

with:

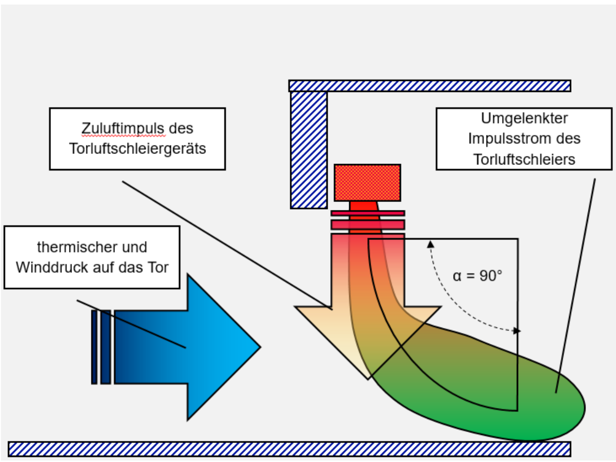
Δp: Total air pressure at the opening, due to wind load und temperature gradient (in Pa)

A_{Door}: Area of the door opening (in m²)

$A_{Curtain}$: Area of the air curtain outlet opening (in m²)

ρ: Density of the air inside the air curtain in (kg/m³)

c: Leaving air velocity of the air curtain in (m/s)



Picture 1: Shielding force of an air curtain, due to the impulse change by the air curtain. Schematic view

Picture 1 shows the basic coherence during the deflection of the supply air curtain.
If the force, required for an exact deflection of the air curtain on the circular path with the radius = door opening height, corresponds to the pressure force on the opening, the opening is considered to be sufficiently sealed off.

The air pressure on the door opening is composed of the air pressure of the wind on the opening and the difference in density resulting from the temperature difference.

The air pressure due to the wind is calculated from:

$$\Delta p_w = c_p \cdot \frac{\rho_W}{2} \cdot c_W^2$$

Formula 2: Dynamic pressure of the wind on a door, taking into account the oncoming air flow conditions

with:

Δp_w: Air pressure on the opening to be shielded, due to the wind load (in Pa)

c_p: Coefficient, due to the oncoming air flow conditions

ρ_W: Density of the outside air (in kg/m³)

c_W: Air velocity (in m/s)

The density difference between the area to be shielded and the outside environment results in the following additional pressure on the opening:

$$\Delta p_{thermic} = g \cdot h_{Door} \cdot \rho_A \cdot \left(1 - \frac{T_A}{T_i}\right)$$

Formula 3: Pressure on the cross section of an open door, due to the temperature differences between the outside and the inside

with:

$\Delta p_{thermic}$: Pressure on the opening to be shielded, due to the density difference (in Pa)

g: Gravitational acceleration: 9.81 (in m/s²)

h_{Door}: Height of the opened door (in m)

ρ_A: Density of the outside air (in kg/m³)

T_i: Inside room temperature (in K)

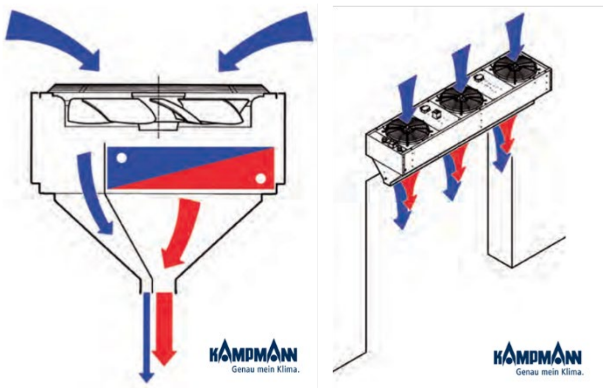
T_A: Outside temperature (in K)

In the further course of this assessment on the efficiency of the ProtecTor system, the pressure force on an open door was defined only on the basis of the temperature difference. On the one hand, the wind direction and the amount change dynamically, on the other hand, the installation situations are so arbitrary that no typical c_p value can be assumed. In this report, the room air temperature of the shielded area is set to 20 °C (293.15 K) and the outside temperature is set to 0 °C (273.15 K).

2.2 The ProtecTor Air Curtain System

In contrast to conventional air curtain systems, the ProtecTor system generates two parallel, plane free air streams. These have different impulses and different temperatures.

In this case, the plane free stream facing the outside environment is considerably cooler, since it is not guided through the integrated heat exchanger.



Picture 2: ProtecTor System made by Kampmann

The idea is, in addition to an effective shielding of the open door, to minimize the thermal losses to the outside environment.

The coordinated air flow path partly over the integrated heat exchanger and partly bypassing it, leads in addition to a different temperature also to a different leaving air velocity and a different air flow distribution.

3. Laboratory Testing

3.1 Experimental Set-up

Picture 3: Experimental set-up in the Kampmann R & D Center and the display of the air exit area where measurements were taken.

In the Kampmann R & D Center, a standard ProtecTor device was installed and measured. For this test not the thermal shielding effect was the focus of the investigation, but the determination of the leaving air velocities in the two air jets of the system.

The average leaving air velocity was determined manually over the respective air exit surfaces.

The system can be operated in 5 operating stages. Here, stages 1, 3 and 5 were measured.

Since exactly these conditions are of relevance for a fluidc analysis by means of CFD, the data thus obtained was transferred as boundary condition directly into the simulation.

The pictures on the left were taken from the Research Report dated 18th February 2014, ProtecTor type: 402076.

3.2 Measurement Data

The readings were recorded by hand with an anemometer and averaged. It must be noted that the exit velocities are due to both temporal and spatial fluctuations. The fans integrated in the ProtecTor system influence a specific distribution of air flow inside the unit. This uniformizes in the direction of the air flow of the air curtain even though it has an uneven distribution at the beginning. Insofar, the measured values listed here should be understood as orientation variables, they however correspond in their dimensions to the planning basis for such systems.

Warm and ambient air streams were measured individually, but at the same operating point. To account for the spatial distribution, measurements were taken at specified measuring points. The measured values were taken centrally in the core area of the air curtain.

The ProtecTor system with a total width of 4 m was measured in the operating stages 1, 3 and 5.

Measuring Points	1	2	3	4	**Average**
Stage 1					
Ambient air stream	12.6	12.2	12.9	15.2	**13.2**
Warm air stream	3.7	3.9	3.8	3.7	**3.8**
Stage 3					
Ambient air stream	18.4	14.5	17.1	20.8	**17.7**
Warm air stream	5.5	6.4	6.1	6.1	**6.0**
Stage 5					
Ambient air stream	24.3	20.3	22.1	24.2	**22.7**
Warm air stream	6.5	8.1	7.6	7.7	**7.5**

Table 1: Measured values from the R & D Report ProtecTor

4. CFD Examination

4.1 Boundary Conditions

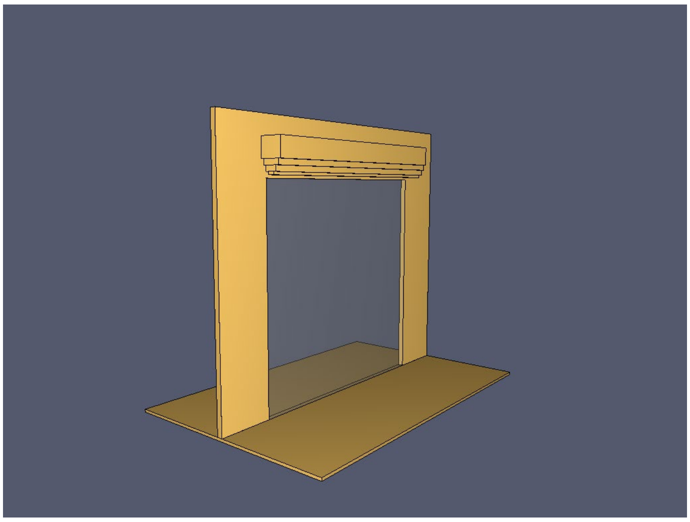
As explained in chapter 2.1 ‘Basis for a Correct Design of Door Air Curtain Systems’, the total pressure in the simulation calculations on the open door is formed exclusively by temperature differences and thus the density differences. According to formula 3 a temperature difference of about 20 K and a door height of about 4 m result in a pressure of between 3 Pa and 4 Pa on the open door. From this, an air volume flow of approx. 20,000 m³/h for the shielding can be derived if the door is 4 m high and 4 m wide. Since this roughly corresponds to the boundary conditions of the investigations on the ProtecTor system in the Kampmann R & D Center (at operating stage 5), these air volume flow specifications were also implemented in the CFD calculations.

Since the additional efficiency and energy-saving effects of the high-pulse and isothermal air stream are of particular interest, the volume flow was introduced through a conventional singular opening (Series of tests: Single) and also through a dual slot row formed in accordance with the structural design of the ProtecTor system (Series of tests: ProtecTor).

The supply air temperatures were also adjusted according to the total output:

Single: 28.75 °C, ProtecTor: 20.0 °C or 35.0 °C.

4.2 Discretisation of the Flow Area



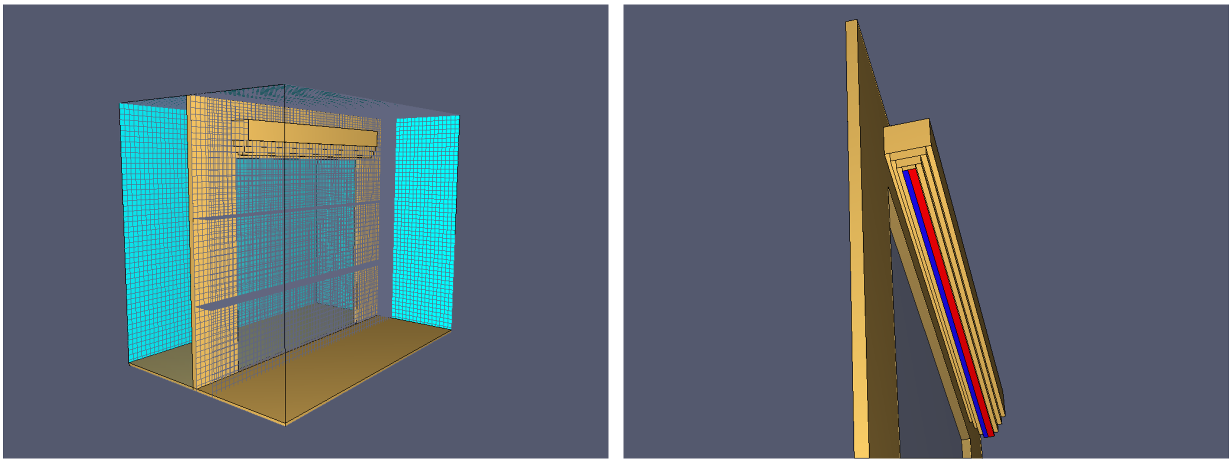
Picture 4 shows the geometry of the case file. A ProtecTor system has been installed right above a 4 m wide and 5 m high door opening**.**

On the outside the ambient air is 0 °C. On the inside, the room is heated to a constant 20 °C.

At time t = 0 seconds, the door is opened and the air curtain is put into operation (Single, or ProtecTor).

Picture 4: CFD-Case ProtecTor, Geometry

To illustrate the flow processes, calculations were done dynamically unsteady. To reduce the resulting high calculation times, the flow area was discretized into different computational meshes. Picture 4 above shows the corresponding meshes to allow calculation in parallel on several processors (in this case 5 meshes or nets). The real time was set to 20 seconds. As can be deduced from the results of the transient calculations, that in all cases investigated, steady flow conditions occur after just 10 seconds due to the high exit air velocities.



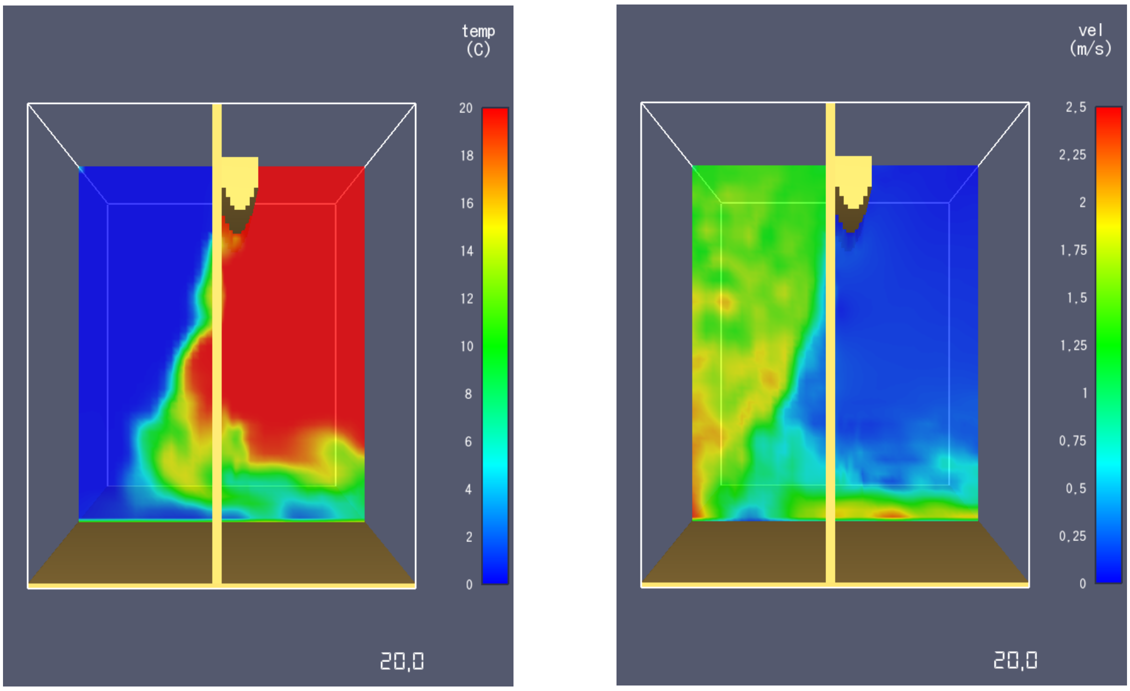
Picture 5: Discretisation of the flow area (left), distribution of the outlet openings (right)

Picture 5 on the right shows the design of the outlet opening of the ProtecTor system. In the case 'Single' both exit slots were loaded homogeneously and identically. In the case 'ProtecTor' the outward-facing part was loaded isothermal and at a higher air velocity according to the investigations of the Kampmann laboratory. The inner slot was loaded correspondingly at a slower air velocity and with higher temperatures.

The calculation periods were between 4 and 8 hours, depending on the case file.

4.3 Simulation Results

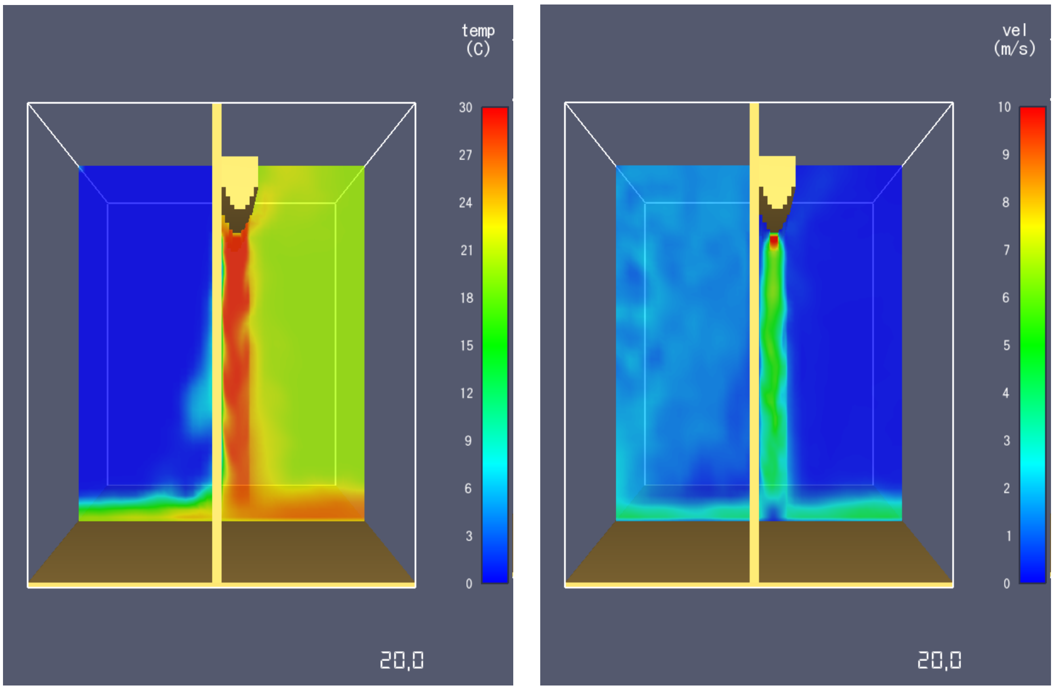
4.3.1 Unprotected Open Door



Picture 6: Temperature field (left) and air velocity field (right) on the room axis, with the air curtain missing or deactivated, after 20 seconds.

Picture 6 shows temperatures (left) and air velocities (right) for an unprotected open door.
Since the right-hand room has no boundary in the simulation, there is no pronounced discharge or recirculation air flow in the upper door area.
In the lower door area though, the cold outside air of ~ 0 °C penetrates the room at up to 2.5 m/s.
As a result, very high heat losses and drafts occur in the occupied area.

4.3.2 Air Curtain System with a Single Air Stream



Picture 7: Temperature field (left) and velocity field (right) on the axis of the room, with the door air curtain switched on, with only one homogeneous stream (single), after 20 seconds

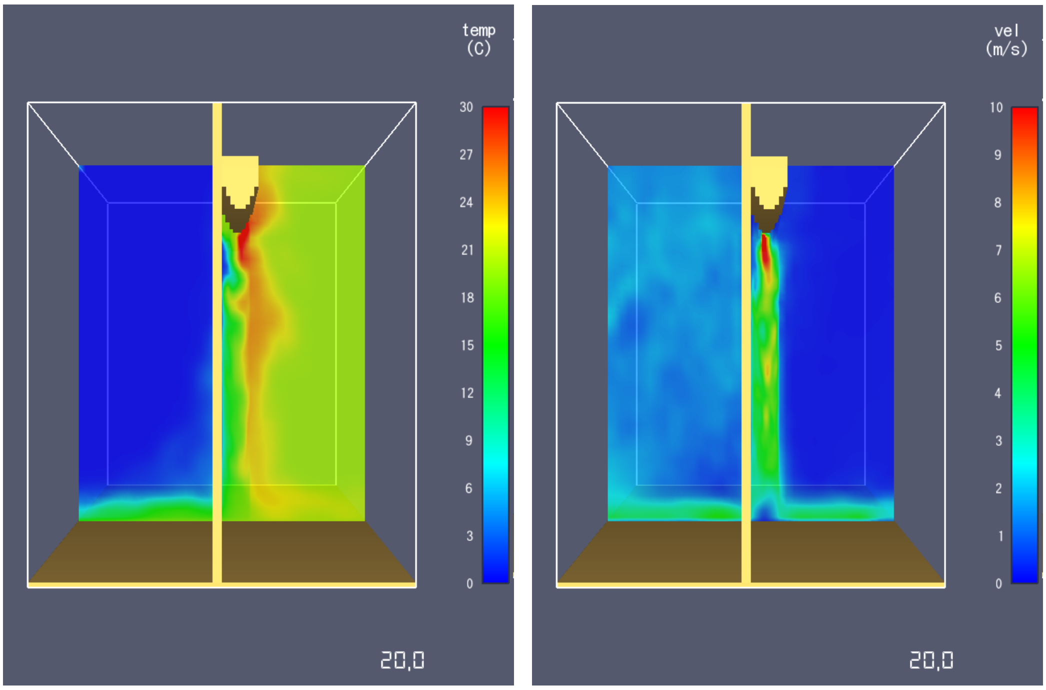
Picture 7 shows the flow field when using a standard air curtain with one air curtain stream.

As expected, the entrance area is completely thermally shielded and separated from the outside area. The room air temperature remains at 20 °C and in the floor area no cold outside air enters, instead warm air from the air curtain enters, which leads to additional heating, and thus to an additional cover of the heating load of the room.

The fact in this test that wind loads do not occur, which as a rule increase the pressure on the door, allows the air stream to flow vertically down to the floor area. The differences in density between the outside and inside do not create at all or do create only a very small deflection of the warm air curtain.

In the floor area outside in front of the door large amounts of warm air can be noticed, which flow with high velocity into the outside environment. These represent obvious losses that cannot be used to the inside as heating power.

4.3.3 ProtecTor Air Curtain System with a Double Air Stream



Picture 8: Temperature field (left) and velocity field (right) on the room axis, with the door air curtain switched on: ProtecTor

Picture 8 shows the self-adjusting flow field when using the ProtecTor system. An isothermal outer air stream (v = 23 m/s) is operated parallel to an internal warm air stream (v = 7.5 m/s). This creates a cooler outer air curtain against the external environment, despite induction of the flanking warm air curtain.

Two direct positive consequences of this process can be seen in the flow depictions.

First, a greater part of the warm air supplied to the air curtain is supplied to the inside of the room to be used for heating.

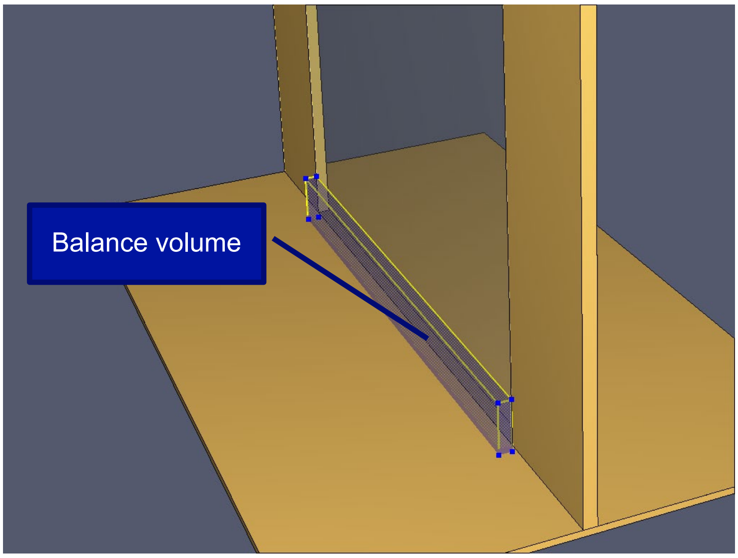
Secondly, after the deflection of a partial volume flow of the air curtain, a significantly lower warm air flow occurs towards the outside, than in conventional systems. This significantly reduces the heat loss to the outside environment.

Another effect of the flanking slower warm air stream, which is not further investigated here, is likely to be the positive influence on the speed decrease of the significantly faster outer air stream. The outer air stream obviously distributes its momentum more slowly to induced air masses and thus achieves higher mean flow velocities over a longer flow path.

5. Efficiency Increase using the ProtecTor System Technology

Obviously, with air curtains, the mass air flow is diverted in the floor area both partly into the inside area and partly into the outside environment.

While the mass air flow supplied to the inside area leads to the support of the heating requirements due to the preheating inside the air curtain, the mass air flow, and hence the heat flow to the outside environment is lost.



Picture 9: Balance area for determining the mean speeds and temperatures that lead to power losses.

In many cases, the air curtain may replace the heating of the room, if the room has a manageable size, subject to its dimensions and use.

If a significant proportion of the heat supplied by the air curtain ist lost to the outside, this proportion is missing for the inside heating.

To analyse this loss, a control volume was introduced into the flow field.

If the calculation results in this control area are continuously stored over the entire transient calculation process and averaged over all volume cells of the balance area, the result is as follows:

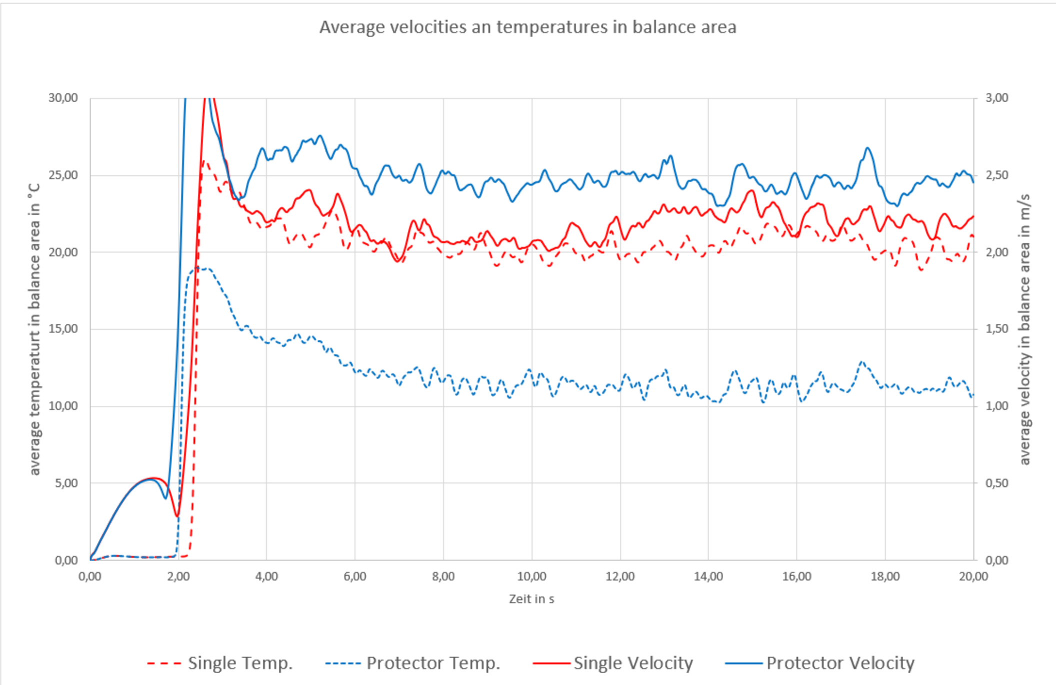


Diagram 1: Depiction of the averaged measured values in the balance area, over the entire calculation time.

The control volume has an effective opening area of 1.6 m² in the direction of the air flow.

When the mean values from the simulation are used, the losses of the different air curtain systems can be determined and put into proportion. The outside temperature was used as reference temperature.

Thus, in general the following applies for the losses, based on the outside temperature:

$$\dot{Q} = A \cdot c_{Curtain} \cdot \rho \cdot c_p \cdot (\bar{T} - T_a)$$

Formula 4: Theoretical loss due to outgoing warm air

With:

$\dot{Q}$: Heat flow losses (in KW)

A: Area which is flowed through towards the outside by the leaving warm air (in m²)

$c_{Curtain}$: Mean air flow velocity of the outflowing air in the control volume (in m/s)

ρ: Density of outflowing warm air (in kg/m³)

c_p: Specific heat capacity of the outflowing air (in kJ/kgK)

$\bar{T}$: Mean air temperature in the control volume (in K)

T_a: Outside temperature (in K)

When subsequently calculating the savings effect: $1 - \frac{\dot{Q}_{Protector}}{\dot{Q}_{Single}}$,

the saving by using the ProtecTor system compared to a single air stream system is approx. 40%.

6. Summary

The aim of this study was the calculation of the efficiency of a dual air stream system (ProtecTor, made by Kampmann) in comparison to single air stream systems (standard air curtains) under given boundary conditions.

The assessment was based on measurement studies on a ProtecTor system and various CFD simulation calculations. The CFD simulation calculations were parameterized with boundary conditions from the laboratory investigations.

Wind load on the door opening was neglected. Instead, a temperature difference of 20 K between the outside environment and the inside was chosen, relevant for the thermal pressure on the opening.

Correctly designed air curtain systems show a good mode of operation for the case tested here with a 4m x 4m door opening. However, all systems show a division into two air mass flows when they reach the floor area. Here, the outgoing warm air mass flow is to be assessed as a loss.

In the simulation calculations, this air mass flow could be balanced for single air stream and dual air stream systems. If, as in the case of the Kampmann ProtecTor system, the outward air stream is isothermal to the room air and significantly faster than the warm air curtain formed parallel and towards the inside, a loss reduction of 40% compared to conventional single stream systems could be demonstrated.

It should be noted that actual savings and efficiencies are affected by operating and thermal constraints.

Steinfurt, 2nd July 2018

Prof. Dr.-Ing. Bernd Boiting