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Cooling of residential buildings in Germany – prospect or dead end?

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In addition to the classical fields of building systems engineering in residential buildings, such as heating and domestic hot water, in Germany increasingly more options such as ventilation and cooling are discussed or used.

The reasons for this approach are different. So increased user requirements for the comfort, the discussion of the climate change or the subjective feeling of very hot summer in the recent past can be named.

While the focus of the observations in residential buildings is mainly on the winter conditions, the summer room climate in the spotlight moves slowly. Intensive considerations about the technical, energetic and economic optimization are required to meet the requirements of the summer room conditioning, which are reflected in the current version of the DIN V 18599.

Energy balancing for cooling of residential buildings in DIN V 18599

Overview of cooling systems

To facilitate the further development of the German energy saving regulations, the standard DIN V 18599 has been revised and released in 2011. One of the main innovations is the balancing for cooling of residential buildings in part 6. The described cooling systems of residential buildings are classified according to **Figure 1**.

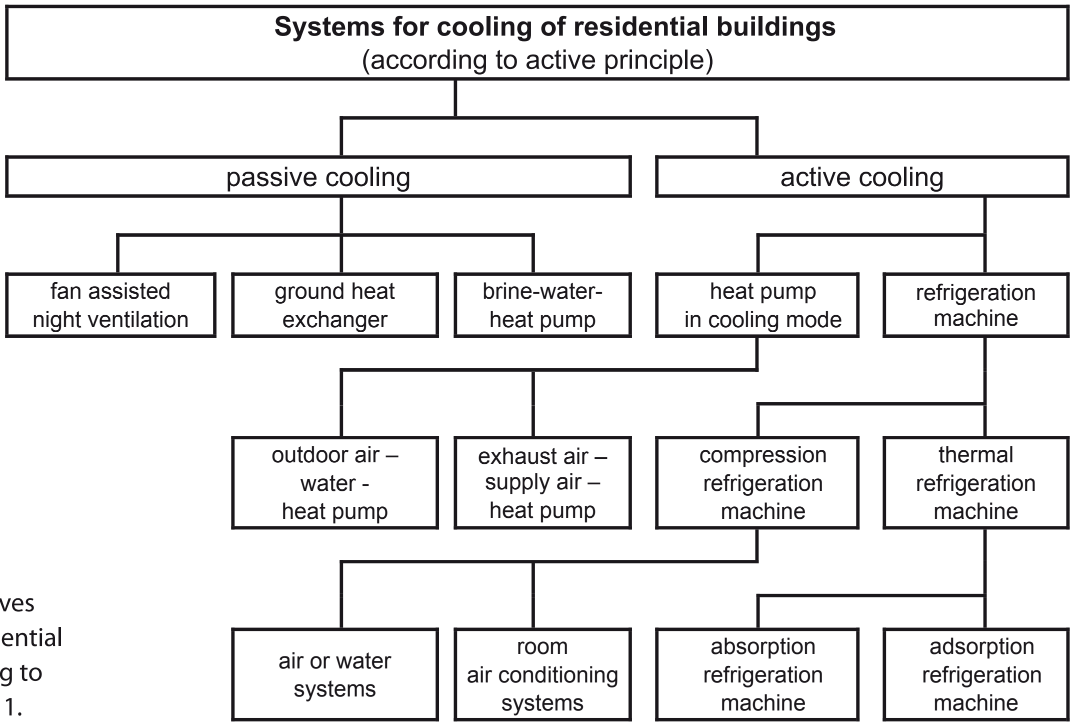

Figure 1. Alternatives for cooling of residential buildings according to DIN V 18599-6: 2011.

The focus is on technical solutions, which are realized in connection with heating or ventilation systems. Typical solutions are e. g. use of heat pumps in cooling mode, but also the passive cooling (including ground heat exchangers or fan assisted night ventilation). Of course, conventional cooling systems, such as compression refrigeration machine and split- / multisplit-systems are mapped.

Precooling versus cooling

A major difference to cooling in non-residential building represents the often restricted performance of the cooling systems of residential buildings. For this a part load factor $f_{c,part}$ and a precooling factor $f_{c.limit}$ are introduced. The part load factor describes the case, that not the entire used area of the building is cooled:

$$f_{c,part} = \frac{A_{N,c}}{A_N}$$

$f_{c,part}$ part load factor
$A_{N,c}$ cooled used area (according to design)
A_N used area

The precooling factor takes into account, that not all cooling systems for residential buildings for a complete coverage of energy need for cooling being interpreted. This can be caused by limitation of cold generation (e.g. ground heat exchanger or fan-assisted night ventilation) or by a limitation of cold control and emission in the room or cold distribution (e. g. air cooling systems or floor cooling):

$$f_{c,limit} = \min(f_{c,limit,g}; f_{c,limit,ced})$$

$f_{c,limit}$ precooling factor
$f_{c,limit,g}$ precooling factor by limitation of cold generation
$f_{c,limit,ced}$ precooling factor by limitation of cold control and emission in the room or cold distribution

The purpose of precooling systems is to reduce the room temperature without guaranteed conditions (such as compliance with Category A according to [EN ISO 7730] irrespective of the cooling loads). The resulting thermal conditions in the room can be exemplarily illustrated on the vertical temperature gradient (**Figure 2**). A cooling is done, however, with the aim of achieving defined comfort conditions even at higher loads and must have corresponding performance reserves.

A precooling (examples of active cooling systems in **Table 1**) can be the result of a limited cooling capacity (e.g. cold generation by free cooling or cooling by radiators as cooling coil in the room).

Table 1. Maximum cooling capacity of selected systems for active cooling according to DIN V 18599-6.

Control Emission Distribution	Generation			
	Outdoor air – water – heat pump	Exhaust air – supply air – heat pump	Compression refrigeration machine	Room air conditioning systems
Ceiling cooling	20 W/m²	–	45 W/m²	–
Floor cooling	20 W/m²	–	20 W/m²	–
Radiator as cooling coil	2.5 W/m²	–	2.5 W/m²	–
Fan coil	20 W/m²	–	45 W/m²	–
Ventilation system	–	5 W/m²	5 W/m²	–
Split / multisplit system	–	–	–	45 W/m²

As a result you get a precooling factor in dependency of

- cold generation,
- cold control and emission in the room,
- cold distribution,
- building type and
- level of heat insulation.

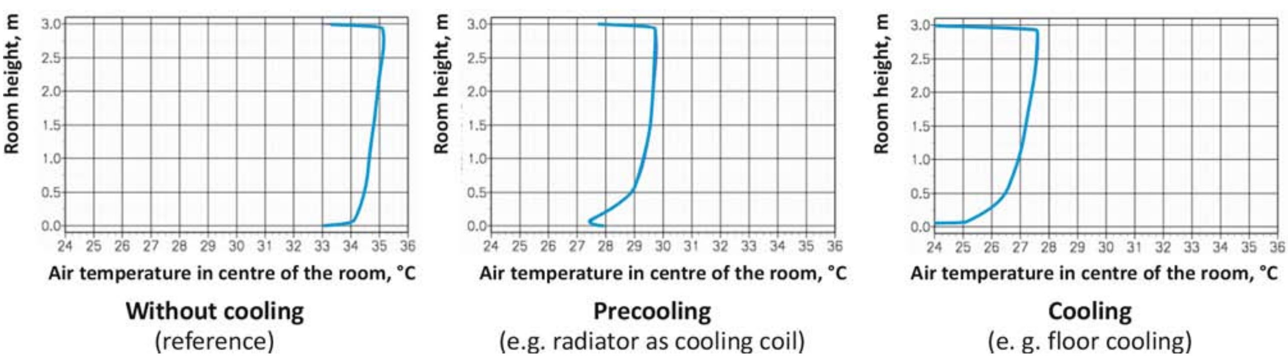

Figure 2. Vertical temperature gradient as a function of the cooling system (examples).

Examples for the precooling factors in a new single-family house show **Table 2** for active cooling and **Table 3** for passive cooling according to DIN V 18599-6.

If the precooling factor reached a value of 1, a full cooling can be realized with the system, the energy need for cooling meets completely. With precooling factors less than 1, the energy need for cooling can be partly covered.

Table 2. Precooling factor $f_{c,limit}$ of selected systems for active cooling according to DIN V 18599-6 – new single-family house.

Control Emission Distribution	Generation			
	Outdoor air – water – heat pump	Exhaust air – supply air – heat pump	Compression refrigeration machine	Room air conditioning systems
Ceiling cooling	1.00	–	1.00	–
Floor cooling	0.98	–	0.98	–
Radiator as cooling coil	0.36	–	0.36	–
Fan coil	1.00	–	1.00	–
Ventilation system	–	0.60	0.60	–
Split / multisplit system	–	–	–	1.00

Table 3. Precooling factor $f_{c,limit}$ of selected systems for passive cooling according to DIN V 18599-6 – new single-family house.

Control Emission Distribution	Generation			
	Brine – water – heat pump	Fan assisted night ventilation	Ground heat exchanger (without bypass)	Night ventilation and ground heat exchanger
Ceiling cooling	0.73	–	–	–
Floor cooling	0.73	–	–	–
Radiator as cooling coil	0.36	–	–	–
Fan coil	0.73	–	–	–
Ventilation system	0.60	0.10	0.44	0.51
Split / multisplit system	–	–	–	–

Generator cooling output and final energy demand for cold generation

The generator cooling output is determined in accordance with part load and precooling effects of the cooling system as well as heat gains during control and emission in the room, distribution and storage:

$$Q_{rc,outg} = Q_{rc,b} \cdot f_{c,part} \cdot f_{c,limit} + Q_{rc,ce} + Q_{rc,d} + Q_{rc,s}$$

$Q_{rc,b}$ energy need for cooling
$f_{c,part}$ part load factor
$f_{c,limit}$ precooling factor
$Q_{rc,ce}$ control and emission heat gains for cooling
$Q_{rc,d}$ distribution heat gains for cooling
$Q_{rc,s}$ storage heat gains for cooling

This results in the annual final energy demand depending on the type of cold generation. For compression refrigeration machines or heat pumps in cooling mode applies:

$$Q_{rc,f,electr,a} = \frac{Q_{rc,outg,a}}{EER \cdot PLV_{av}}$$

$Q_{rc,f,electr,a}$ annual final energy demand for cold generation (electricity input)
$Q_{rc,outg,a}$ annual generator cooling output
E_{ER} energy efficiency ratio
P_{LVav} mean part load value

Table 4 using the example of new single-family house with default values to show the resulting seasonal energy efficiency ratio (SEER = EER * PLVav).

Table 4. Seasonal energy efficiency ratio SEER of selected systems for active cooling according to DIN V 18599-6 6 – new single-family house.

Control	Generation					
	Outdoor air – water – heat pump	Exhaust air – supply air –heat pump	Compression refrigeration machine		Room air conditioning systems	
			Outgoing temperature cooling		Split	Multi-split
			6°C	16°C		
On / Off	2.11	2.55	2.18	2.95	1.90	1.40
Inverter controlled	3.10	–	–	–	2.83	2.77
Digital scroll	–	–	2.37	3.19	–	–

Similarly for the annual final energy demand for cold generation (heat input) of thermal refrigeration machines:

$$Q_{rc,outg,therm,a} = \frac{Q_{rc,outg,a}}{\zeta \cdot PLV_{av}}$$

$Q_{rc,outg,therm,a}$ annual final energy demand for cold generation (heat input)
$Q_{rc,outg,a}$ annual generator cooling output
ζ nominal heat capacity ratio
P_{LVav} mean part load value

Background of the characteristic values in DIN V 18699-6 : 2011

Definition of load profiles

For the assessment of the efficiency of different technologies it was necessary to have information about the trend of a cooling load of a refrigeration period time. These calculations were carried out in accordance to different structural building properties, to reflect the influence of different building age classes. Therefore a classification according to the building age respectively the insulation standard was done (**Table 5**).

For each residential building class beyond the influence of typical parameters like thermal storage capacity, share of window area, building orientation, type of shading system was studied and divided in 3 categories of buildings (**Table 6**), in which for all variants the thermal heat protection in summer is maintained.

As a result it could be shown, that a differentiation of building age is necessary in the standardization process.

In addition to the building properties the kind of building usage is responsible for the trend of the cooling load. In this context the usage-specific internal thermal gains for different rooms of a residential building (living room, bedroom, bath, kitchen) from EN ISO 13791 were used and a load profile for a children's room and humidification effects in all profiles were added. Based on the room profiles averaged flat-profiles were derived for single-family houses (EFH) and multi-family houses (MFH), which correlate in the daily total amount with the values for the internal heat sources of DIN V 18599-10 (45 Wh/m²d for single family houses and 90 Wh/m²d for multi-family houses). The determined usage profiles were validated using measured data for 10 different residential buildings and showed a good agreement in this field.

Taking into account the boundary conditions described a lot of cooling load profiles were determined for the single- and multi-family houses. **Figure 3** shows the frequency distribution of the cooling hours in residential rooms of single-family houses in comparison to the complete flat as an exemplary for the building Category 2.

All living rooms show a similar frequency distribution of the cooling hours like the complete flat. As a result of the investigations it was found that there is no need for a differentiation between different rooms of a flat.

Table 5. Classification according to the residential buildings age.

Class of residential building	Old building (low insulation standard)	Old building (ordinary insulation standard)	New building (high insulation standard)
Built year	to 1995	Since 1996	New building
Insulation standard	–	German "WSchV 1995"	German "EnEV 2009"
U-value external wall	1.0 W/m²K	0.5 W/m²K	0.28 W/m²K
U-value external window	2.5 W/m²K	1.8 W/m²K	1.3 W/m²K
U-value roof, top floor ceilings	0.8 W/m²K	0.3 W/m²K	0.2 W/m²K
U-value wall or ceiling covered unheated rooms / ground covered walls	1.0 W/m²K	0.5 W/m²K	0.35 W/m²K

Table 6. Categorization of typical parameters for the cooling demand.

Building category	Category 1	Category 2 (standard)	Category 3
Thermal storage capacity	Thermal mass class S	Thermal mass class M	Thermal mass class L
Share of window area	10% of ground floor, 2 windows, 1 direction	20% of ground floor, 3 windows, 2 directions	30% of ground floor, main facade fully glazed
Building orientation	Main window area orientated to the east	Main window area orientated to the west	Main window area orientated to the south
Window type (g-value)	Double glazing g = 0.8	Heat protection glazing g = 0.6	Solar protection glazing g = 0.4
Type of shading system	Internal glare protection activated only in case of direct solar radiation	External solar protection activated only in case of direct solar radiation	External solar protection activated from an amount of 200 W/m²

Therefore residential buildings also in the cooling case can be calculated with the existing single-zone model.

Cooling capacity

According to **Figure 3** the maximum frequency of the cooling hours occurs at very low cooling load. Thus cooling systems with a low cooling capacity could reach comfortable room temperatures in this part load range.

In the standardization process the maximum value of the cooling load in the load profile corresponds to the maximum required cooling capacity. If the installed system can‘t deliver the complete required cooling capacity it is defined as a "part cooling system". This capacity deficit could be a consequence of a limited cooling capacity of the generation and distribution system (e.g. an air based Free Cooling system with a ground heat exchanger) or of the control and emission system (e.g. cold water flowed floor heating).

Part load values

The efficiency of a chiller is usually described through the energy efficiency ratio EER. The nominal cooling capacity is required only in few hours of the year. According to **Figure 3** cold generation systems in residential buildings work the most time in the part load range. The reduction of the cooling capacity comes from an integrated capacity control system, which can be designed as a continuously control (e.g. variable speed control) or a staged system (e.g. ON-OFF operation). The more efficient this capacity control system works, the more efficient the complete cooling system is.

To map this effect in the normative value method, the part load value was established. Through multiplication with the nominal energy efficiency ratio EER, the seasonal energy efficiency ratio SEER of a chiller can be calculated. The SEER value characterizes the relation between the annual net energy demand for cooling and the necessary required final energy demand. A cooling system with high energy efficiency (low final energy demand) must have a high nominal energy efficiency ratio EER and additionally a high part load value PLV.

A variety of part load values for different system boundary conditions and various kinds of building usages contains the German standard DIN V 18599-7: 2011 in annex A for non-residential buildings. Taking into account a possible capacity limitation of the residential buildings control and emission and distribution systems and based on the typical load profiles for residential buildings (**Figure 3**) part load values PLV for active cooling systems in residential buildings were determined for the first time. **Figure 4** shows the part load values PLV of a reversible outdoor air – water heat pump in the cooling mode exemplary for existing single-family houses with an ordinary insulation standard (German "WSchV 1995").

In general the inverter-controlled heat pump is more energy efficient than the ON-OFF-controlled heat pump because it has higher part load values in cooling mode.

If the specific cooling capacity of the control and emission system decreases fewer than 20 W/m² the cooling capacity of the heat pump must be reduced. This correlates with a reduction of the energy efficiency. At the same time the precooling factor decreases fewer than the value of 1.0. For that the cooling capacity limitation of

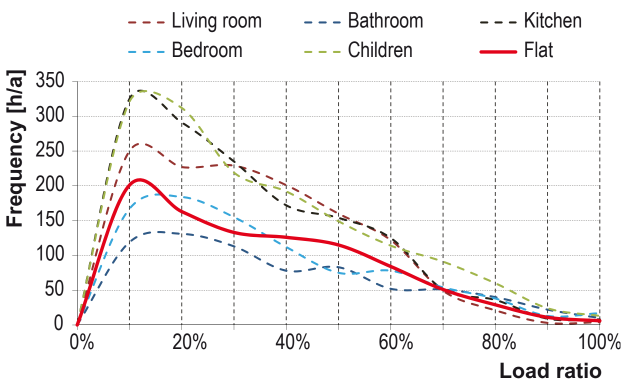

Figure 3. Frequency distribution of the cooling hours in different rooms of existing single-family houses with ordinary insulation standard (German "WSchV 1995", building Category 2).

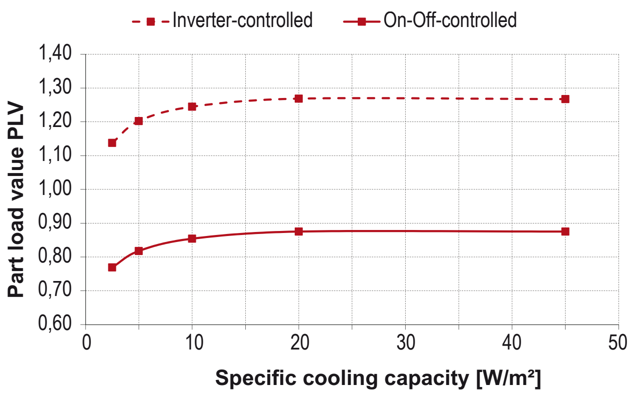

Figure 4. Part load value PLV of a reversible outdoor air – water heat pump in existing single-family house with ordinary insulation standard (German "WSchV 1995", building Category 2).

the control and emission system is responsible, because not in the whole cooling period the required cooling capacity could be transferred into the room. **Figure 5** shows the trend of the precooling factor in dependence of the cooling capacity limitation of the control and emission system exemplary for existing single-family houses with different insulation standards.

The precooling factor describes the relationship between the provided cooling energy of the installed cooling system and the required overall cooling energy demand as an area-weighted average of all rooms in a single family house. This factor tends to be slightly higher in good insulated buildings than in low insulated old buildings.

At all systems decreases the transferred cooling energy rate if the control and emission limitation increases. At air based ventilation systems with a cooling capacity of maximum 5 W/m² only the half of the required annual cooling energy demand may be provided.

Conclusion

Reversible heat pump sale shows, that cooling of residential buildings in Germany leaving the niche in recent years. As reasons, increased user requirements for the comfort, the discussion of the climate change or the subjective feeling of very hot summer in the recent past can be named.

Nevertheless, in Germany no general trend for cooling of residential buildings should be noted. Structural measures for the summer heat protection in addition to moderate weather conditions are the reason for preferring compensation of cooling loads to using technical systems. However, in new residential buildings can originate cooling loads by approximately 30 W/m². These are always more frequently at least proportionally covered by technical systems that take over most other functions (heating, ventilation) in the building.

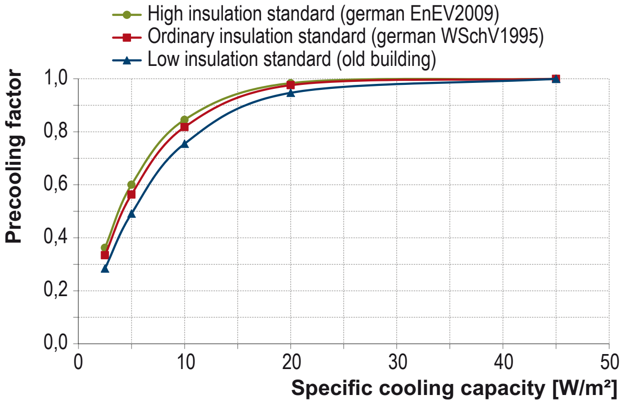

Figure 5. Precooling factor in dependence of the cooling capacity limitation of the control and emission system (building Category 2).

With current German standard DIN V 18599: 2011 cooling for residential building is part of the framework of the energy saving regulation (EnEV) for the first time in Germany. Attention is paid to the peculiarities in comparison with air conditioning of non-residential buildings.

Due to the typical cooling of residential buildings, which often is realized as an additional feature of existing equipment (e.g. in combination with heat pumps or ventilation), a new definition of the cooling target arises.

In DIN V 18599-6: 2011 precooling and part cooling effects are described and quantified to enable comparison of cooling systems both from the perspective of the energy balance and thermal comfort. The focus is consequently on typical residential cooling systems without neglecting the conventional refrigeration. The energetic balance method provides the opportunity to create an adequate cooling effect with efficient technologies usually without major additional investments in residential buildings and to localize at the same time inefficient systems in advance. ■

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Part 2: Net energy demand for heating and cooling of building zones
Part 6: Final energy demand of ventilation systems and air heating systems for residential buildings
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