Passive Cooling Measures for Single-Family Houses

MAGDALENA ZWIEHOFF
M.Sc. Power Engineering
University of Stuttgart
Institute of Building Energetics
Magdalena.Zwiehoff@mwgroup.net

Within this paper a variation study of passive cooling measures – measures without technical effort – of single-family houses is presented. Constructive and user caused changings are implemented into a basic version of a typical single-family house. TRNSYS is used as simulation software. Measures are considered that reduce both, heat entry into the building and internal heat loads. Shading, night-time ventilation, glazing, insulation standard, internal masses and internal thermal loads are examined. The heating and the cooling demand of the building is compared with the basic version.

Keywords: passive cooling, single-family house, simulation with TRNSYS, shading, night-time ventilation, glazing.

During the past decades requirements concerning the insulation of residential buildings have increased. Thus, transmission heat losses through the building envelope have been reduced and improved air tightness causes lower ventilation losses. The building is decoupled more and more from external climatic conditions and the utilization of the building has a higher impact on the energy consumption. Most measures ensuing from energy-saving regulations focus on lowering the heating demand. They can further generate a cooling demand during the hot season, if an upper temperature limit is defined. In residential buildings, especially single-family houses, cooling is not currently common, whilst it is considered state of the art in office buildings.

For the cooling of buildings there are active measures which need auxiliary power and measures without technical effort. This paper focuses on measures without technical effort. Passive measures subsume all methods which decrease heat fluxes into the building and reduce internal thermal loads.

The paper examines passive cooling measures of single-family houses in a variation study using the simulation software TRNSYS. In the first step a basic version of a typical single-family house is created. Then, constructive and user caused changes are implemented in the model. The heating and cooling demand of the building is compared with the basic version.

Method

Cooling measures without technical effort are implemented in a model of a single-family house that serves as basic version.

The following categories of measures are examined: shading, night-time ventilation, glazing, insulation standard, internal masses and internal thermal loads.

The simulation software TRNSYS is used for the variation study. TRNSYS (TRaNsient System Simulation) is a software that can simulate the thermal behaviour of buildings and plants. The time of simulation is one whole year, meaning 8.760 hours and the simulation time increment is 10 minutes.

As a result, the building energy demands of the models are calculated according to the guidelines VDI 2067 Part 10 [1]. It is used as evaluation criterion since no technical measures with additional energy effort are to be discussed.

Basic version

Building geometry

The basic version of the building is designed for four persons. It consists of eight rooms located on two floors. The total habitable area of the house is A = 144 m². The ridge of the roof is aligned north to south, so the slopes of the saddle roof point east and west. **Figure 1** shows the general arrangement of the building model.

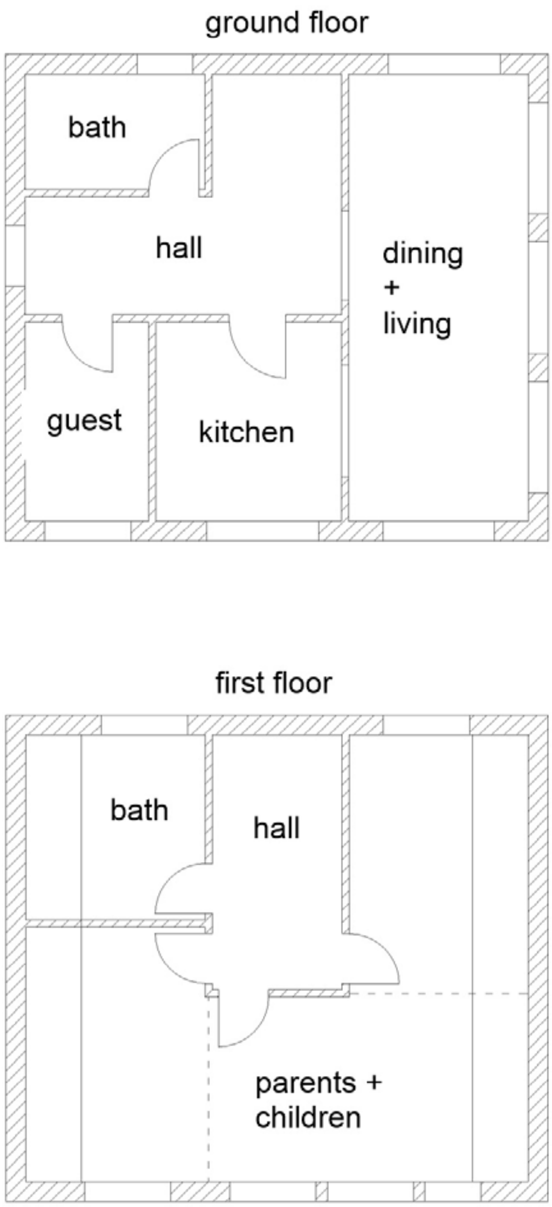

Figure 1. General arrangement of the building model.

The building is constructed according to the insulation standard of the German Energy Saving Ordinance (EnEV 2009). It has double-pane heat insulation glazing and lightweight internal walls. All rooms of the basic version are unshaded and are exposed to direct solar radiation.

Boundary conditions of the simulation

Climate data of North Rhine-Westphalia (North-West part of Germany) are used for the simulation.

In order to model the resident's behaviour, the air change due to infiltration varies depending on occupancy. The determination of the air changes refers to DIN EN 15251:2012-12 [2]. When unoccupied, all rooms will have an air change of $n = 0.11\ h^{-1}$. During busy time the air change augments to $n = 0.60 – 0.64\ h^{-1}$ for each room according to the ratio between room area and room volume.

Utilization

The utilization of the building is determined by temperature inputs, attendance profiles of the residents and load profiles of the electrical appliances. The thermal heat emitted by persons, by electrical appliances and by lighting is part of the energy balance of the room. In **Table I** the required heating and cooling temperatures of each room are shown. During night-time the air temperature set value is lowered by 4 K.

Table I. Required heating and cooling temperatures of each room.

Rooms	Heating temperature in °C	Night-time reduction* in °C	Cooling temperature in °C
Bedroom, living room, kitchen, guest room, hall	20	16	26
Bathroom	24	20	26

* between 11:00 p.m. and 06:00 a.m.

Simulation variants

Within the variation study 13 cooling measures without technical effort are investigated. The study aims to evaluate the measures according to their energy efficiency and to determine the measure that leads to the minimal cooling demand of the building.

Shading

Sunshade is often used to protect rooms against heat entry due to radiation. It reflects and absorbs part of the radiation and lowers the amount which enters the room. The variation study examines the efficacy of external shutters, external blinds whose blades are positioned at a 45 degree angle and internal shading. The reduction factor F_C indicates the amount of the total incoming radiation which enters the room with the shading in place. According to DIN 4108-2:2011-10 [3] the reduction factor for external shutters is set to $F_C = 0.1$, for external blinds to $F_C = 0.25$ and for internal shading to $F_C = 0.75$. If the ambient temperature exceeds the limit of $\vartheta = 5°C$ and if the solar radiation exceeds 50 W/m², the shading will be lowered.

Night-time ventilation

This concept intends to raise the air change in the building during night-time in order to remove the solar and internal heat loads occurring during day-time. The air change is afforded by natural ventilation; no mechanical equipment is used. The augmented air change is added to the existing. Two variants of night-time ventilation are simulated. The air change is set to $n = 2\ h^{-1}$ and $n = 4\ h^{-1}$. Night-time ventilation will be turned on if the ambient temperature is at least 2 K below the room temperature and off if the indoor temperature falls below $\vartheta = 20°C$.

Change of glazing

A variant analyses the impact of reducing the total energy transmittance (*g-value*). The value describes the proportional amount of energy which heats up the room due to direct transmission and secondary heat dissipation mechanisms (irradiation, convection). The building of the examined variant is equipped with triple-pane heat insulation glazing. The total energy transmittance of the glazing is $g = 0.407$ (basic version: $g = 0.598$). The heat transfer coefficient (*U-value*) of the window is not changed.

Variation of insulation standard

The modification of insulation standard is part of the study. The quality of the overall insulation is numbered by the transmission heat loss referred to the exterior surface H_T'.

- In a variant the insulation standard is increased according to German Energy Saving Ordinance (EnEV 2013). The transmission heat loss referred to the exterior surface is $H_T' = 0.36\ W/(m^2·K)$ (basic version: $H_T' = 0.40\ W/(m^2·K)$).
- In another variant the insulation standard is reduced according to German Energy Saving Ordinance (EnEV 2002). The transmission heat loss referred to the exterior surface is $H_T' = 0.49\ W/(m^2·K)$.
- A building erected between 1984 and 1994 is examined as well. The outer walls are not insulated and single-pane windows with $U = 2.83\ W/(m^2·K)$ are used. The transmission heat loss referred to the exterior surface area is $H_T' = 1.01\ W/(m^2·K)$. Additionally the air change due to infiltration is that of an old building.

Consideration of internal masses

The simulation software TRNSYS uses a multiple-zone model which considers the heat capacity of the air volume and of the walls. No thermal masses of furnishing are taken into account. The following variants investigate the effect of an increased heat capacity.

- The internal walls are designed solid. Sand lime brick is used as construction material. The thickness of the wall is not changed but the heat transfer coefficient of the solid wall is ten times higher than of the lightweight wall.
- This variant takes into account the influence of furnishing. Furnishing is modelled as internal walls which influence the thermal behaviour of the room due to their mass. They also exchange radiation with their surrounding surfaces.

Reduction of internal thermal loads

Internal thermal loads normally consist of heat gains from residents, electrical appliances and lighting. During the heating period the energy demand is lowered by internal thermal loads, whereas in case of cooling a greater cooling load has to be dissipated. In order to decrease the cooling demand a reduction of internal thermal loads is modelled.

- The users' behaviour, including the occupancy as well as the utilization of electrical appliances and lighting, is changed. The basic version schedules that one parent stays at home and one parent as well as the two children are absent over the day. In a variant the scenario is changed so that all residents are absent from morning to evening on weekdays. Consequently, no electrical appliances are used during that time.
- Electrical appliances and lighting emit thermal energy. In the simulation the assumption is made that the thermal power output equals the electrical power consumption. In a variant the thermal output of electrical appliances is reduced by assuming appliances of the best energy efficiency class available on the market.

Table II gives a summary of all 13 simulated variants.

Table II. Summary of the simulated variants.

Variants	Characteristics	Numbering
Shading	External shutters	Variant 1
	External blinds	Variant 2
	Internal shading	Variant 3
Night-time ventilation	Air change = 2 h^{-1}	Variant 4
	Air change = 4 h^{-1}	Variant 5
Glazing	Reduction of total energy transmittance	Variant 6
Insulation standard	Increase according to EnEV 2013	Variant 7
	Decrease according to EnEV 2002	Variant 8
	Old building	Variant 9
Internal masses	Solid internal walls	Variant 10
	Influence of furnishing	Variant 11
Inner thermal loads	Change of user behavior	Variant 12
	Reduction of thermal output	Variant 13

Results

The results of the TRNSYS simulation are plotted in **Figure 2**. The heating and cooling demands in kWh/a of the basic version (B) and of the variants (V1 to V13) are shown.

The basic version requires 4.975 kWh/a for heating and 5.568 kWh/a for cooling of the single-family house.

Table III illustrates the relative demands with the basic version being the reference. Due to the implemented measures the cooling demands of 11 variants are reduced, in return, the heating demands of 8 variants are increased. Mostly, a reduced cooling demand causes an increased heating demand.

Table III. Percental comparison with the basic version.

	Heating demand in %	Cooling demand in %	Total demand in %
B	**100**	**100**	**100**
V1	110	18	62
V2	107	28	65
V3	100	98	99
V4	117	73	94
V5	125	60	91
V6	99	54	75
V7	92	106	99
V8	131	84	106
V9	510	43	263
V10	96	91	93
V11	99	104	102
V12	101	93	97
V13	103	93	77

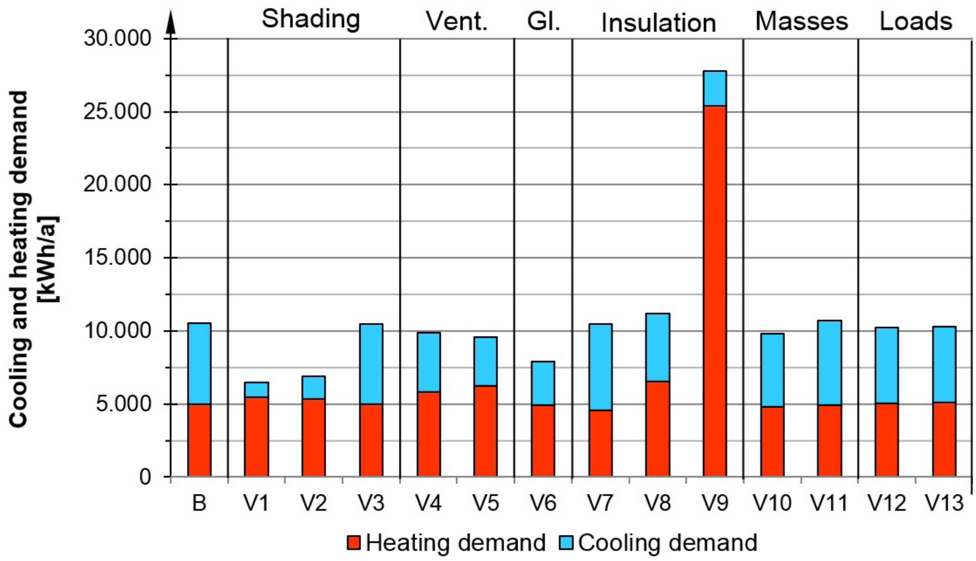

Figure 2. Plot of the results.

The results are discussed below:

- V1: External shutters are most effective regarding the cooling demand and the total demand. The cooling demand can be lowered to 1.007 kWh/a, i.e. a reduction by 82 % of the cooling demand of the basic version. During seasonal transition time the shutters withhold solar gains for heater support. That is the reason why the heating demand increases by 10 %.
- V2: External blinds are the next best option. For cooling 1.579 kWh/a are required corresponding to a reduction by 72 %. Heating demand increases by 7 %. The advantage of blinds compared to shutters is the higher light transmission into the room.
- V3: Regarding energy savings, internal shading is not reasonable. No effect is achieved concerning the heating demand, the cooling demand decreases by a mere 2 %.
- V4: It is quite profitable to increase the air change during night-time. The cooling demand of the simulated building decreases by 27 % down to 4.051 kWh/a. Night-time ventilation is active all year, i.e. also during wintertime. This fact leads to an increase of heating demand by 17 %.
- V5: Doubling the air change lowers the energy demand for cooling by 40 % whilst increasing that for heating by 25 %. In total 9 % of the energy demand can be saved.
- V6: Glazing with a lower total energy transmittance is the third best option to decrease the total energy demand. It is an advantage that they reduce the cooling demand by 46 % without increasing the heating demand.
- V7: A higher insulation standard gives rise to a diminished transmission heat loss. Thus, the heating demand decreases by 8 %, whereas the cooling demand increases by 6 %.
- V8: A lower insulation standard raises the heating demand by one third, to 6.540 kWh/a. In return, the cooling demand of the building is reduced by 16 %.
- V9: Old buildings have almost no insulation and quite a high infiltration rate through the building envelope. The missing insulation decreases the cooling demand by 57 %. In contrast, the heating demand jumps up to 25.375 kWh/a, meaning a sharp rise to more than fivefold.
- V10: Solid internal walls act as a heat storage. During heating period the walls absorb the heat and emit it into the room later, resulting in the heating demand being reduced by 4 %. On days with a high room temperature the walls absorb part of the cooling load which leads to a decrease of the cooling demand by 9 %.
- V11: The heating demand of the model which examines the influence of furnishing is decreased by just 1 %. This can be explained by the rather low heat capacity of the furnishing. Contrary to expectations the cooling demand increases by 4 %. This fact can be explained as follows: Furnishing is represented as additional internal walls whose surfaces absorb heat radiation from outside. The modelling of furnishing as internals walls is thus not realistic.
- V12: If the user behaviour is modified, assuming a reduced occupancy of the building, cooling demand is decreased by 7 % whereas the heating demand increases by 1 %.
- V13: The variant with reduced thermal output of electrical appliances achieves similar results. Cooling demand is lowered by 7 %, heating demand increased by 3 %.

Summary and conclusion

The heating and cooling demand of 13 variants of passive cooling measures of a single-family house compared to a basic version is examined. The study aims to determine the measure that reduces the total energy demand of the building.

The results show that external shutters are most effective regarding the reduction of the total energy demand for heating and cooling. They reduce the total energy demand by 38 %, external blinds which still reduce it by 35 %, being the second best option. The building equipped with glazing with a lower total energy transmittance requires 25 % less total energy demand. ■

References

[1] VDI 2067: Economic efficiency of building installations - Energy demand for heating, cooling, humidification and dehumidification. September 2013.

[2] DIN EN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. December 2012.

[3] DIN 4108-2: Thermal protection and energy economy in buildings - Part 2: Minimum requirements to thermal insulation. October 2011.