German Energy Conservation Regulation - basics and examples

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ABSTRACT: The German energy conservation regulation "Energieeinsparverordnung (EnEV)" came into effect on February 1st, 2002. New requirements for the planning and performance of the building envelope and the technical systems for heating, hot water supply, and ventilation have been introduced. In addition to an upgrade in the overall standard, EnEV shows the potential of using the underlying calculation procedures as a planning tool that offers new energy saving approaches in buildings.
This paper presents a description of the structure and the requirements of the Energy Conservation Regulations. Also, the calculation of heat use, based on the German Standard DIN V 4108-6, derived from the European standard EN 832, and primary energy use, based on DIN V 4701-10, are presented. Calculation examples show the impact of possible compensation measures on thermal insulation systems vs. technical systems, and the influence of single measures on primary energy use. The consequences regarding planning and performance are shown.

1 INTRODUCTION

Since the oil crisis in the 1970s, the first developments in energy regulations regarding the building sector in Germany emphasised the transmission losses of the building envelope, i.e. U-values. In the 1980s, the next step towards an energy balance of buildings allowed for the calculation of the heat demand, including ventilation losses, as well as internal and passive solar heat gains. Due to an increased interest in CO_2 reduction, more stress was put upon the building service system and the calculation for energy use was integrated.

In February 2002, the German Energy Conservation Regulation "Energieeinsparverordnung" (EnEV) became valid, formulating requirements for primary energy use and including additional conditions, such as limiting transmission losses and providing thermal comfort in summer.

1.1 *Definitions*

The heat use or heat demand, i.e. the heat to be delivered to the heated space in order to maintain the internal set-point temperature, and the heat required for hot water represent constructional conditions of the building.

The energy use additionally takes into account the heat losses, gains and efficiencies deriving from the building service system.

The final energy use covers the heat demand caused by heating, hot water, the technical plant, and auxiliary equipment within the building, i.e. the bought energy. In Figure, 1 the systems' boundaries can be seen.

The primary energy use additionally includes the primary energy process outside of the building, i.e. production, transformation and transport of the energy to the interface of the building edge.

2 REQUIREMENTS

There are several building sectors covered by the requirements of the EnEV. Generally the EnEV applies to buildings with:
– normal internal temperature higher than 19°C, i.e. in residential and office buildings, schools, etc.
– decreased internal temperature above 12°C, i.e. mostly in industrial buildings/halls.

Different requirements are formulated for:
– the new building sector
– existing buildings, i.e. in the case of structural alterations and extensions

– the obligatory retrofitting and maintenance of technical equipment, and insulation quality, following special conditions.

Additional requirements relate to:
– the limitation of transmission losses to ensure the insulation quality of the building envelope,
– a sufficient thermal comfort in summer,
– the airtightness of the building envelope,
– minimum requirements for thermal insulation and thermal bridges
– the commissioning of boilers
– the hot water supply's distribution system

2.1 *Requirement values*

For new buildings with normal internal temperature, and extensions to existing buildings, the main value to verify is the **annual primary energy use** of the building Q_P referring to:
– the heated volume V_e for non-residential buildings [kWh/m³a]

or,
– the heated floor space A_N for residential buildings [kWh/m²a] (also marked with the small type q_P).

The calculation is based on an energy balance including heat losses and gains. Figure 1 illustrates the distinction of primary energy and final energy use for heating, hot water and ventilation (final energy). The energy use for cooling and lighting is not included in this approach.

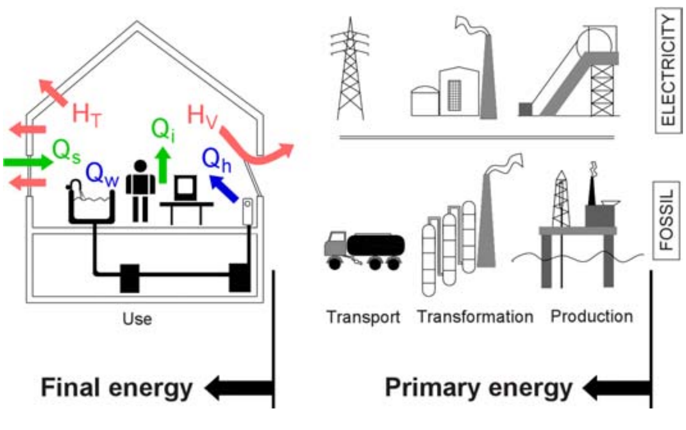

Figure 1. Principle of the building energy balance, the definition of primary and final energy and the influencing variables.

For buildings with decreased internal temperature, the **transmission losses referring to the heat loss surface** A, i.e. H_T' are essential. This value also expresses the additional requirements for limiting the transmission losses for buildings with normal internal temperature. The H_T'-value of a building is similar, but not equal, to an average U-value of the building envelope.

For structural alteration of existing buildings, the requirements affect **maximum U-values** of the concerned building parts. Alternatively, the calculation of an energy balance similar to that of new buildings is possible.

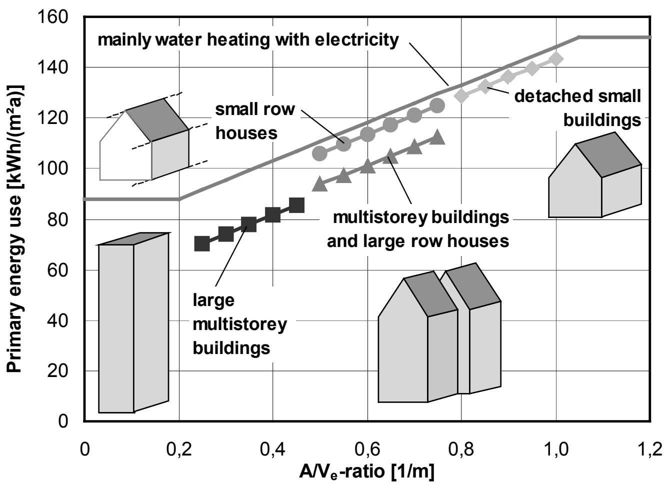

Figure 2. Requirement value Q_P (primary energy use) for residential buildings. Distinction: different systems for hot water generation.

The maximum values for the annual primary energy use and the transmission losses are related to the ratio of the heat loss surface to the heated volume of the building, i.e. the A/V_e-ratio, which represents the compactness of the building shape. As for the combined system used for central heating and hot water supply in residential buildings, the calculation of the maximum primary energy use additionally takes the heated floor space, A_N , into account. The required value for residential buildings is shown in Figure 2.

3 CALCULATION METHOD

The calculation of the primary energy use (see also Figure 1) has been derived from the European Standard EN 832 and adapted into the German Standards DIN V 4108-6 and DIN V 4701-10:

$$Q_P = (Q_h + Q_w)\, e_P \tag{1}$$

Q_P = annual primary energy use [kWh/a]; Q_h = heat demand; Q_w = heat demand for hot water supply (only residential buildings, const.); e_P = conversion factor for buildings' service systems (heating, hot water, ventilation), i.e. reciprocal value of efficiency, including primary energy process.

The calculation methods for the efficiency of the technical equipment are defined in the German Standard DIN V 4701-10. As a simplified method several (> 70) pre-defined building service system designs are available in the 'Beiblatt' (supplement) of this standard and have been fully calculated. Additionally, a set of equations is provided, allowing for the detailed calculation of every part of the system, provided that all technical parameters are available.

3.1 *Heat demand calculation*

The heat demand according to DIN V 4108-6, or EN 832 respectively, represents the energy balance of the building:

$$Q_h = Q_l - \eta\, Q_g \tag{2}$$

Q_l = heat loss due to transmission and ventilation [kWh/a]; η = utilization factor for the gains; Q_g = internal and passive solar heat gains.

The calculation of the energy balance is based upon a monthly method for a single-zone building model or, alternatively, a seasonal calculation as a simplified method for residential buildings with a limited fraction of glazed facades.

3.2 *Features of heat demand calculation*

3.2.1 *Transmission losses and thermal bridges*

The transmission losses of the envelope include additional losses due to thermal bridges. The symbol for this, represented by the correction value ΔU_{WB} [W/(m²K)], is multiplied with the heat loss surface A:

$$H_T = \sum F_i U_i A_i + \Delta U_{WB}\ A \tag{3}$$

F_i = temperature correction factors due to decreased temperature differences, U_i = thermal transmittance and A_i = area of all elements of the building envelope; ΔU_{WB} = correction value for thermal bridges (with 'WB' for 'Wärmebrücke' = thermal bridge); A = heat loss surface (= sum of A_i).

Generally ΔU_{WB} = 0.10 W/(m²K). The 'Beiblatt' (supplement) of DIN 4108 contains a catalogue of exemplary solutions for connections of building components. The usage of these guidelines allows for the reduction/bonus of: ΔU_{WB} = 0.05 W/(m²K).

Furthermore, the detailed calculation of the thermal bridges causes a reduction in the calculated influence due to thermal bridges to less than 0.05 W/(m²K). This detailed calculation assumes that the linear transmittance ψ and the length of the two-dimensional thermal bridges are known. The values are listed in manuals and electronic catalogues (Hauser et al. 1998).

3.2.2 *U-value calculation*

For the calculation of thermal transmittance (U-value) of the building components, the standards and the EnEV refer to DIN EN ISO 6946 (opaque components), and DIN EN ISO 10077-1 (transparent elements).

The required thermal design values are available in DIN EN 12524 or national/European product standards, i.e. DIN V 4108-4 for Germany. Furthermore, the 'Deutsches Institut für Bautechnik DIBt' (German Institute for Building Technology) publishes design values for both measured building components and elements under standardised conditions, and components of heating and ventilation systems ('Bauregelliste').

3.2.3 *Ventilation losses and airtightness of the building envelope*

In order to ensure a defined air change rate and air flow in the building, a sufficiently airtight building envelope is necessary. It must also be guaranteed that when using a ventilation system with heat recovery system (heat exchanger, air/air heat pump or a combined system), the air exchange will completely take place via the ventilation unit.

In order to ensure the airtightness of the building envelope, the method that is usually used is based on a blower door test, i.e. the measurement of the air change rate with a pressure difference of 50 Pa. For buildings with ventilation systems, these measurements are obligatory.

The equation for the ventilation losses is generally formulated as follows:

$$H_V = \rho_L\ c_{pL}\ n\, V \tag{4}$$

$\rho_L\ c_{pL}$ = density and specific heat capacity of air; n = air change rate (ACH); V = volume of air in heated zone.

The value of the air change rate includes the influence of the airtightness of the building envelope, i.e.:

- generally n = 0.7 1/h for naturally ventilated buildings
- for naturally ventilated buildings with proven airtightness: n = 0.6 1/h
- for buildings with ventilation systems and with proven airtightness: n = 0.6 1/h
- for buildings with extract ventilation systems and with proven airtightness: n = 0.55 1/h.

3.3 *Boundary conditions for heat demand calculation*

DIN V 4108-6 contains a set of boundary conditions for the calculation of the annual heat demand in the context of EnEV (monthly balance calculation). The predefinitions concern:

- uniform average climatic data (solar radiation, ambient/external temperature)
- a simplified approach for calculation of internal heat gains, i.e. 6 W/m² for office buildings and 5 W/m² for others
- shading correction factor for windows 0.9
- simplified definition for heated floor space A_N = 0.32 V_e and volume of air in heated zone V = 0.76 V_e (small buildings) or V = 0.8 V_e (other buildings),

- distinction of light and heavy constructions to assess the effective internal thermal capacity for calculation of gain/loss ratio,
- intermittent heating with cut-off mode (residential buildings 7 hrs., non-residential buildings 10 hrs.)

3.4 *Calculation of the building service system*

The building service system is the energy used for technical building equipment, including heating, hot water supply and ventilation. The energy use for cooling and lighting is not included in this approach.

By taking the primary energy process (production, transformation and transport) into account, the primary energy use is calculable.

The different efficiencies and heat losses due to heating and ventilation systems are related to energy flows, as shown in Figures 3 to 5. They are used to obtain the energy required for heating and hot water supply. The auxiliary energy, i.e. electricity used for pumps, fans, controls, etc., is also part of the energy balance approach.

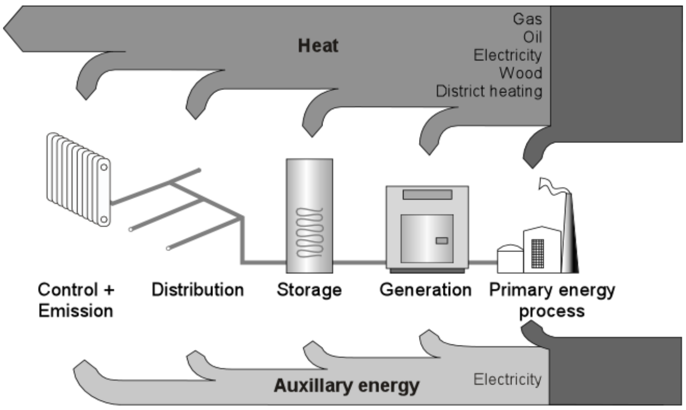

Figure 3. Heat losses and energy flow due to heating system.

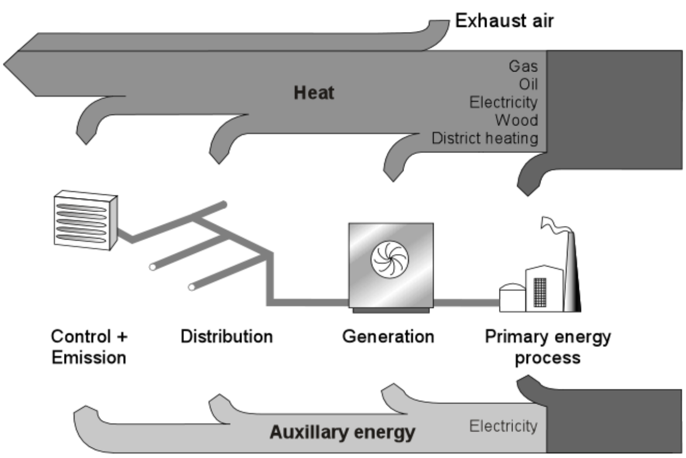

Figure 4. Heat losses and energy flow due to ventilation systems.

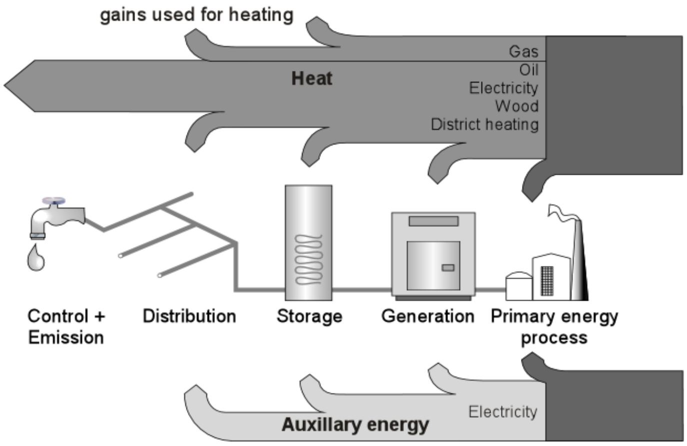

Figure 5. Heat losses and energy flow due to hot water supply.

4 EXAMPLES

In order to show the effects of the requirements of the EnEV and the calculation approach, two simple residential buildings, a one-family building (Example 1) and a multifamily building (Example 2), with varying constructional and technical components, have been used. The parameters are given in the Figures.

4.1 *Base case*

The buildings as shown in Figures 6 and 7 are naturally ventilated with proven airtight building envelopes, thermal bridges, in accordance with 'Beiblatt' (supplement) of DIN 4108, and low temperature boilers for combined heating and hot water preparation.

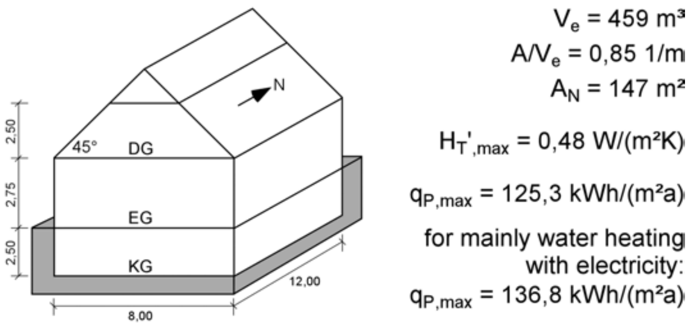

Figure 6. Example 1: Isolated one-family building; Calculation example and data.

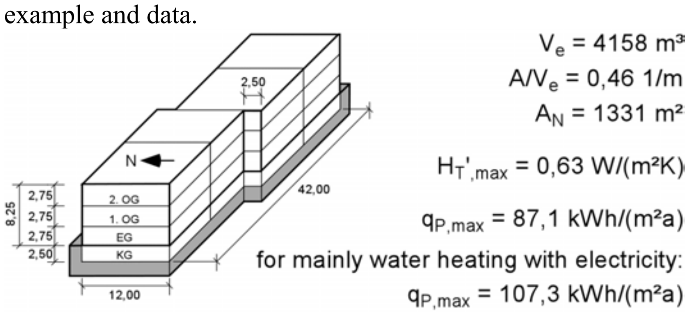

Figure 7. Example 2: Multi-storey residential building; Calculation example and data.

4.2 *Variation*

Variations of the building concern the constructional sector, i.e. the alteration of the building airtightness (Var. 1) and the design of the thermal bridges (Var. 2 and 3).

The other variations in regards to the building's service system are based on improved generation using a condensing boiler for heating and hot water supply (Var. 4, 6, 7 and 8), and additional usage of recovered energy, i.e. a ventilation system with heat recovery (Var. 7) and solar hot water preparation (Var. 8).

Optimized hot water preparation includes placing the stored water inside the heated volume and has no circulation pump (Var. 5). Var. 5 differs in the case of the multifamily building, i.e. electrical instantaneous water heaters are placed locally, in combination with a small storage of water.

The condensing boiler unit and its distribution is also placed inside the heated volume, i.e. the apartment (Var. 6). In the last variant, the boiler is replaced by a ground water heat pump with a floor heating system (Var. 9).

Table 1. Variation definitions

Var.	Description
0	Base case
1	Without proved airtightness, n = 0.7 1/h
2	Without 'bonus' for thermal bridge, $\Delta U_{WB} = 0.05$ W/(m²K)
3	Optimized thermal bridge (exemplary detailed calculation), $\Delta U_{WB} = 0.02$ W/(m²K)
4	Condensing boiler
5	Example 1 (one-family building): Optimized hot water preparation, i.e. storage within heated space, without circulation Example 2 (multifamily building): localized electrical instantaneous water heater in combination with a small storage of water
6	Condensing boiler unit, centrally in each apartment, distribution and installation in heated space
7	Condensing boiler, ventilation system, heat recovery 60%
8	Condensing boiler, solar hot water preparation
9	Ground water heat pump, electrical supplementary heating, floor heating system

4.3 *Results*

The results in Tables 2 and 3 show the effect of the variants as defined in Table 1. The basic principle of the calculation and variants is as follows: the U-values of the building envelope are varied in order to fit the results to the EnEV requirements, i.e. the maximum primary energy use q_P or the limitation of transmission losses H_T'. The standards for the building examples are given in Figures 6 and 7. The bold type values indicate which value is valid for the variant.

The tables also give the conversion factor for the building's service system (heating, hot water, and ventilation), e_P, due to the respective system used for the variant and the final energy q_E.

Table 2. Example 1: Calculation results and boundary conditions of variants. U-value indices: AW = walls, doors, D = roof, upper floor, G = Cellar. Windows: U = 1.4 W/(m²K), g = 0.58.

Var.	U_{AW}	U_D	U_G	H_T'	e_P	q_E	q_P
	W/(m²K)				-	kWh/(m²a)	
0	0.23	0.21	0.35	0.38	1.61	108.2	**125.2**
1	0.20	0.19	0.21	0.35	1.61	108.2	**125.1**
2	0.17	0.15	0.21	0.38	1.61	108.3	**125.2**
3	0.31	0.24	0.35	0.38	1.61	108.2	**125.2**
4	0.35	0.22	0.36	0.41	1.49	108.2	**125.2**
5	0.50	0.24	0.38	0.46	1.35	109.8	**125.3**
6	0.50	0.24	0.50	**0.48**	1.27	106.2	121.1
7	0.42	0.27	0.50	0.46	1.34	105.2	**125.1**
8	0.50	0.24	0.50	**0.48**	1.27	103.5	120.8
9	0.50	0.24	0.50	**0.48**	0.99	31.5	94.4

Table 3. Example 2: Calculation results and boundary conditions of variants. U-value indices: AW = walls, doors, D = roof, upper floor, G = Cellar. Windows: U = 1.4 W/(m²K), g = 0.58.

Var.	U_{AW}	U_D	U_G	H_T'	e_P	q_E	q_P
	W/(m²K)				-	kWh/(m²a)	
0	0.30	0.27	0.48	0.46	1.45	77.6	**87.1**
1	0.23	0.21	0.33	0.40	1.45	77.5	**87.0**
2	0.25	0.21	0.35	0.46	1.45	77.6	**87.1**
3	0.36	0.27	0.55	0.46	1.45	77.6	**87.1**
4	0.41	0.27	0.54	0.51	1.35	77.6	**87.1**
5	0.41	0.27	0.56	0.51	1.66	71.0	**107.3**
6	0.52	0.37	0.56	0.58	1.23	77.8	**87.1**
7	0.54	0.44	0.56	0.60	1.19	74.7	**87.1**
8	0.54	0.44	0.56	0.60	1.19	76.8	**87.1**
9	0.56	0.50	0.59	**0.63**	0.90	22.9	68.8

Due to the usage of electrical water heating in Var. 5 (Multi-storey building), the maximum value for the primary energy use differs from the other cases, see also parameters in Figure 7.

A graphical view of the calculation results is given in Figures 7 and 8. The bar chart contains the annual primary energy use in [kWh/(m²a)] split into the gain (negative, left), and loss (positive, right) portions.

- recovered energy for generation
- internal heat gains
- heat demand due to building envelope transmission losses, including passive solar heat gains, i.e. windows, walls, doors, building parts concerning the cellar and thermal bridges (notice: the yellow bars for windows are hardly visible because losses and gains are almost equal)
- heat demand for ventilation (including heat recovery due to ventilation system in Var. 7) and hot water supply
- energy use of the building service system (heating, hot water and ventilation), i.e. losses due to emission, distribution, storage and generation

– portion due to the effectiveness of the primary energy process, i.e. extraction, transformation and transport.

The primary energy use of the building as displayed in Tables 2 and 3 (border case of maximum allowed value) results from the balance/difference of the energy portions. The portions affected by the variation are indicated by a bold lined frame.

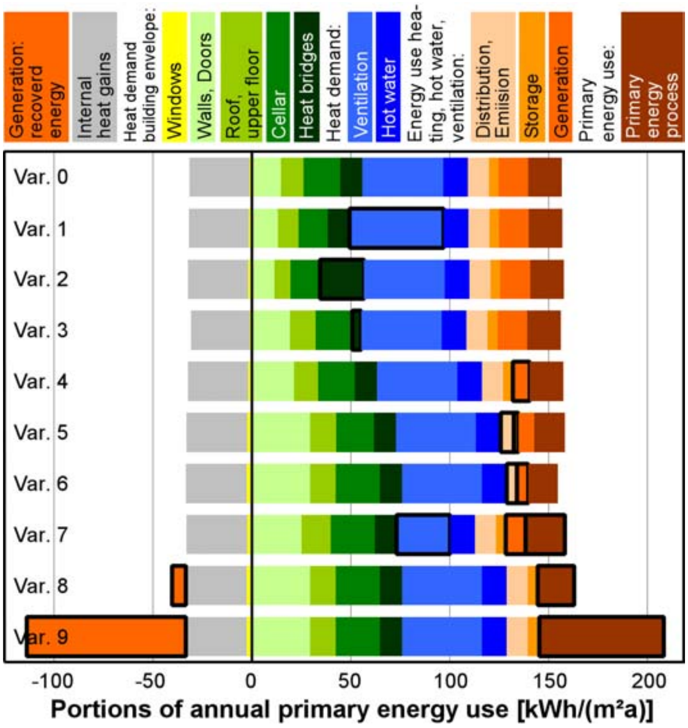

Figure 8. Example 1: Schematic visualization of energy portions for the described one-family building, i.e. base case and variations.

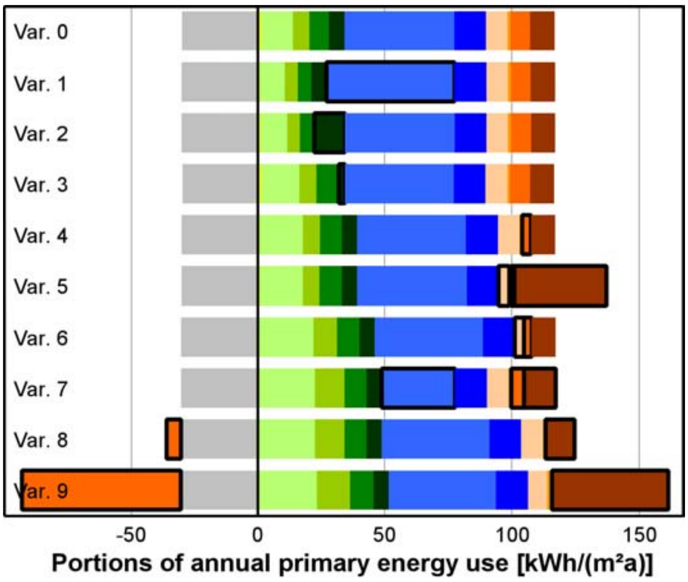

Figure 9. Example 2: Schematic visualization of energy portions for the described multifamily building, i.e. base case and variations. For legend, see Figure 8.

4.4 *Comparison and evaluation*

The comparison of the variants shows the potential for compensation among the different portions of the energy use. The exploitation of the varied U-values of the building envelope, up to the EnEV requirements, does not represent a reasonable building design and is only used for this comparison.

As shown in Figures 8 and 9, the requirements for the insulation quality of the building envelope increase in Var. 1 and Var. 2, due to either the higher air change rate or transmission losses of thermal bridges. They decrease with the optimization of the thermal bridges (Var. 3). The condensing boiler causes a reduction in generation losses (Var. 4).

Example 1 (one-family building): An optimized hot water preparation affects the losses due to distribution and storage (Var. 5), and, additionally, the generation losses in the case of a compact boiler unit (Var. 6). This variant also causes the change in the required value, i.e. the limitation of the transmission losses according to EnEV is valid, and set to 0.48 W/(m²K).

Example 2 (multifamily building): Due to the usage of electrical water heating in Var. 5, the maximum value for the primary energy use differs from the other cases, see also parameters in Figure 7. The U-values of Var. 4 and Var. 5 are similar, i.e. the increased limitation of the primary energy for buildings with mainly electrical hot water preparation causes comparable conditions in regards to the usage of a condensing boiler (Var. 4). The compact boiler unit (Var. 6) increases all portions of the losses due to the building service system, yet, compared to Example 1, limitation of the primary energy use instead of the transmissions losses is still essential.

The condensing boiler combined with a ventilation system using heat recovery (Var. 7) causes a decrease in the ventilation heat use and an increase in the primary energy losses due to the electricity demand of the ventilation system.

As for the additional solar hot water preparation (Var. 8), the portion of recovered energy moves the generation losses to the "gain-side" and, in the case of the one-family building, the limitation of the transmission losses according to EnEV is valid, instead of the primary energy use. The heat pump (Var. 9) shows similar effects, i.e. the increase of recovered energy and the limitation of the transmission losses. The gains due to recovered energy compensate for the primary energy losses caused by the electricity demand of the heat pump.

5 CONCLUSION

The German EnEV uses an advanced calculation approach by integrating the effectiveness of the building service system, in order to verify the optimization of the whole building system, in regards to energy conservation and CO_2 reduction. This approach corresponds to the EC draft directives on Energy Performance (EU 2001, Beerepoot 2002).

The calculation examples show the potential of the calculation methods, especially the monthly balance according to EN 832, and the compensation in the constructional vs. technical components of the building.

Beyond the limitation of primary energy use, the calculation method can also be used as an advanced planning tool in obtaining an optimised building system.

Several software products enable convenient usage of the calculation methods regarding 'simple' EnEV calculations, all the way up to advanced analyses of the building performance including, e.g. multi-zone models according to EN 832 (EPASS-HELENA 2002).

In order to improve the capabilities, the planning process should include the building envelope **and** the building service system simultaneously and, at an early stage.

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