Presentation of the energetic deviation through the living module construction inside a factory hall

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***Abstract* - In regards to the project "dre:RAUM" a calculation tool for an air-heating pump, running with photovoltaics, and a version with solar thermal energy should be created. Furthermore, a thermal simulation of the building should provides information over the maximum degrees in summer and winter of the living module (without an installation of heat supply). The variant of the air-heating pump reaches an absolute deviation of the degree of self-sufficiency of 1,6% and the variant of solar thermal energy achieves 5%. The thermal building simulation obtained a living module temperature of 32°C in summer and -2,9°C in winter. Therefore a heat supply has to get integrated in the living module in the winter scenario. For the summer scenario additional measures can be derived.**

1 Introduction

„dre:RAUM“ stands for a sustainable use of existing building structures, which should command a decentralised, renewable energy supply. Due to the particular use of living modules within an old factory hall results a living climate, that is difficult to verify with the available standardisation. For this reason, a thermal building simulation should give additional information. Furthermore, a simple calculation method should be created, to get a first impression of the needed thermal energy.

2 State of the Art

In WS 16/17 a first prototype, consisting of a timber frame construction with timber insulation, was built. A wall was made in a straw-loam-construction. In addition, a first thermal simulation of the building was conducted in the past. Due to the stationary conditions of the simulation, it is only of limited informational value and needs to be reviewed.

3 Aim

In the subsequent work the following question should be clarified with the help of thermal building simulations: Is it possible for the living modules to warm up sufficiently in winter through internal profits (waste heat from people and devices) or is an additional heat supply necessary?
In the regarded summer scenario, the simulation should give information about the temperature in the hall and living module to make a statement, whether there is a comfortable living climate or not.
A further goal of this paper is to develop a tool to create heat requirement calculations and the degree of self-sufficiency in the heating sector for a solar thermal heat pump as well as for one, which runs with photovoltaic electricity.

4 Tool

To get a first impression of the needed thermal heat for the domestic hot water preparation that is provided through a solar heating system or a heat pump, which runs by photovoltaic electricity, a simple Excel-Tool will be developed. In addition, the tool should assist to determine the degree of self-sufficiency.

4.1 *Calculation schedule creation*

The figure below shows a calculation schedule to determine the degree of self-sufficiency of solar thermal power and photovoltaics.

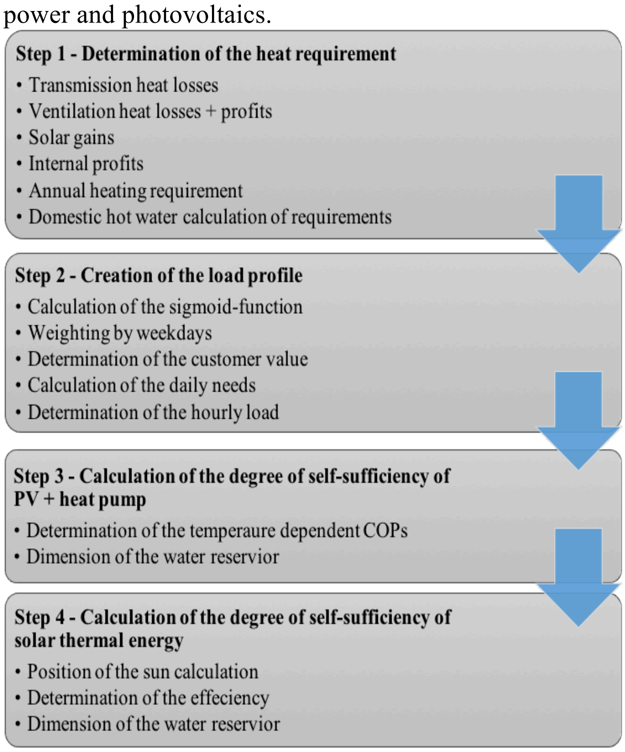

Figure 1: Calculation schedule of the tool

In the first step, the demand for thermal heating and domestic hot water of the module will be determined.

The next step will be to transform the annual heat requirement into an hourly load profile. Subsequently the determination of the degree of self-sufficiency will be execute.
Not every single issue will be discussed in detail.
Background information on each calculation step can be found here: Step 1 [1,2], Step 2 [3], Step 3[4], Step 4 [5,6].
The calculation of the heat requirement is based on the annual balance method of EnEV 2007, which is no longer valid, but is still a good method to estimate the heat requirement.
In the following, a variance to the common calculation method of EnEV 2007 will be mentioned, as there will be discrepancies through the low personal living space and the shading of the hall.

4.2 Internal profits

Waste heat due to people and devices like refrigerator, TV etc. are denoted as internal profits.
The calculation of the internal profits is based on an across the board internal profit of 5 W/m^2 according to the EnEV. 5 W/m^2 is the mean for a typical single-family house. Due to a compressed living space of approximately 10-12 m^2 the internal profits spread over a smaller living space. Therefore, the lump sum area value can be taken as too low.
The assumptions of the absolute heat gain assist to calculate a new areal internal heat gain for a more precise calculation. The following assumptions have been made:

TABLE 1: INTERNAL PROFITS OF THE MODULE

heat source	heat output per hour	operating time
1 person, sitting, dormant	100W [7] 50W – averaged over 24h	12h/d 24h/d
refrigerator	40W [7]	24h/d
other devices	10W	24h/d

In total results a constant heat output of 100W per hour. In case of a reference area of 11qm, the areal value is 9 W/m^2.
This effects a nearly doubling of the internal profits from 5 to 9 W/m^2.
Following the adjusted calculation is not like in the EnEV 2007 prescribed:

$$Q_i = 22 * A_N \qquad [22\text{kWh/m}^2\text{a}] \tag{1}$$

But:

$$Q_i = 40 * A_N \qquad [40\text{kWh/m}^2\text{a}] \tag{2}$$

The number 40 is composed by multiplying the internal profit Q_i of 9 W/m^2, the duration of the heating period from 185 days and the energy content of the air with 0,024 kWh.

4.3 Solar gains

Solar gains arise through incident sunlight, which will be absorbed from parts within the building (furniture, wall) and reduces the heating demand thereby.
The surrounding hall occurs an increased shading compared to a detached house. This is why the losses resulting from shadow gets quantify with Google Sketchup. This program shows the position of the sun and shading for every time of day.
Thereby, a distinction is made between the first row, which gets solar radiation primary from the window facade of the south, and the second row, which receives the direct sunlight mainly from the skylights.
In the course of this, a proportion will be made out of the theoretical sunshine duration SD0 and the practical sunshine duration SD. As of a radiated surface of 50% it will be called, by definition, unshaded in the following. The second row is located approx. 6,00m behind the first row. This value corresponds, similar to the design of the photovoltaic system, to an unshaded subject without influences through the front row on 21.12 at 12 o'clock. Further information may be found under [8].

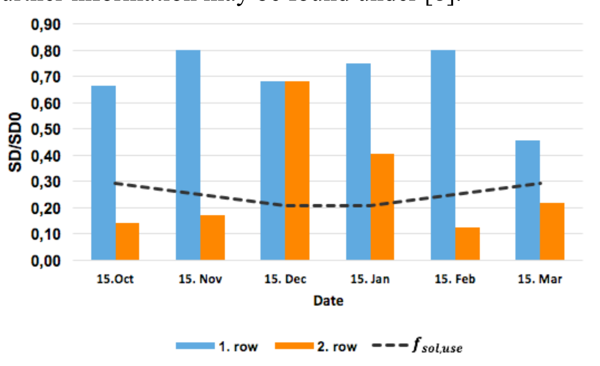

Figure 2: Comparison of the solar irradiation duration of the window surfaces

As the graphic shows, the first row of the living module is irradiated between 50-90% of the potential radiation duration.
The second row achieves values between 20-38%, only a very low sun in December reaches a value of 68%.
With the following formula, the solar degree of utilisation $f_{sol,use}$ can be defined. This indicates the usable proportion, which is used as basis in calculation methods [9].

$$f_{sol,use} = 0{,}2 + 0{,}1 \cdot \left(0{,}5 \cdot \cos\left(\frac{4\pi}{365} \cdot DOY + \pi\right) + 0{,}5\right) \tag{3}$$

The solar gains of the first row can be determined with the general calculation method (according to EnEV 2007 270kWh/m^{2}a). For the second and following rows a deduction has to be included to factor the reduced solar radiation into the calculation.

4.4 Validation of the Tool

To quantify the calculation tool for the degree of self-sufficiency it has to be compared to a study of self-consumption and self-sufficiency degrees [9].

Table 2 shows the input variables:

TABLE 2: INPUT PARAMETER - VALIDATION OF THE HEAT PUMP

heating energy requirement	13.298	[kWh]
cooling energy requirement	297	[kWh]
domestic hot water	2.684	[kWh]
household electricity requirement	4.000	[kWh]
hot water temperature	60	[°C]
hot water storage size	200	[l]
size of photovoltaics	7	[kWp]

As result, a degree of self-sufficiency of 19,64% was calculated without regarding the energy required for cooling. This is in contrast to a degree of self-sufficiency of 20% from [9]. By adding the energy required for cooling an acceptable degree of self-sufficiency can be assumed, because of the overlapping of the air conditioning and the PV electricity generation (max. + 1,93%).
The validation of the solar thermal energy calculation tool was executed on the basis of the following parameters:

TABLE 3: INPUT PARAMETER - SOLAR THERMAL

domestic hot water requirement	4.100	[kWh]
heating demand	8.900	[kWh]
hot water storage size	2000	[l]
aperture area	15	[m^2]

On the foundation of the software "Valentin Software T Sol 2016" a comparative calculation was performed. Thereby a degree of self-sufficiency of 30% was reached. The own tool achieved a proportion of 35%. The systematic deviation is not within the acceptable tolerance limit and by this it only helps for a rough assessment.

5 CFD SIMULATION

As previously described, a Computational Fluid Dynamic (CFD) Simulation of a summer and winter case will be malingered, to provide information about the climate of the hall and module. The meteorological data of temperature, irradiation and wind are based on the database of the weather station from the meteorological observatory Lindenberg.
With the calculated factors from the Site PV GIS the horizontal irradiation values can be adjusted to an inclined and azimuth modified surface.
The simulation takes place 72 hours and is transient. With this a certain periodical transient oscillation can be reached and the effect through overnight cooling of the temperature in the hall in summer and the warming in winter can be inspected.
Selected has been the periods with the lowest and highest temperatures. It is an old factory hall with skylights, partially front-glazing and a gate. The gate and the roof windows are opened in summer, closed in winter.
Moreover, the living module, as described in Point 4.3, will be simulated with internal profits. In the following graphics a vertical cut is set in each case to show the temperatures of the hall, module and outside air.

5.1 *Summer scenario*

The results show that at 15 o'clock by an outside temperature of approx. 31°C the same temperature is reached inside the hall, caused of the active ventilation of the hall with an opened gate and skylights. The insight temperature of the module is with 32°C slight above the temperature of the hall, due to the internal profits.

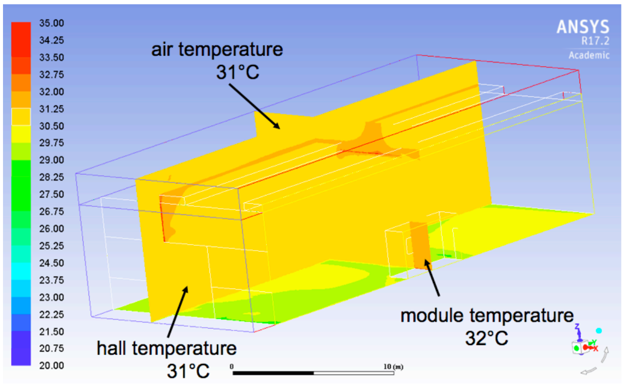

Figure 3: summer scenario - hall temperature at 15 o´clock

To compare: according to DIN 4108-02, a comfortable inside room temperature should stick to 25-27°C depending on the residence. 1200 hours of over-temperature degree are permitted. (An hour of over-temperature degree occurs, when the temperature of the module is over the comfortable room temperature for an hour. 1 kelvin = 1Kh, 3 kelvin = 3Kh per hour).
Direct sunlight to the module surface, which wasn't simulated, would lead to an additional warming. This is why blinds or similar, measures according to DIN 4108-02, are necessary to restrict the direct sunlight for transparent components. Overall the room temperature could be considered as critical. It has to be mentioned that it is an extreme value consideration in this context and so these are the highest temperature periods of the year.
For this reason, a yearly simulation of the hours of over-temperature degree is recommended to determine the frequency of excess, so that additional measures, which are possibly connected with expenses, could be prevented.

5.2 *Winter scenario*

Statements about how the good insulation of the module in combination with the internal profits affects the temperatures of the module should be made for winter.

Figure 4 shows the temperatures of the hall and module for 7:30 am. The temperature of the hall is between -5 to -2,9°C and is therefore 8 to 6°C higher as the outdoor temperature. The internal temperature of the module is, despite the internal profits and the good insulation of the module, between -2,9 to 2,2°C. Thus an additional heat source is mandatory for this living module.

In this case, a lower outdoor temperature for the heat supply can be taken into consideration.

With that a reduced heat supply and thereby reduced investment costs for an additional regenerative energy supply can be achieved.

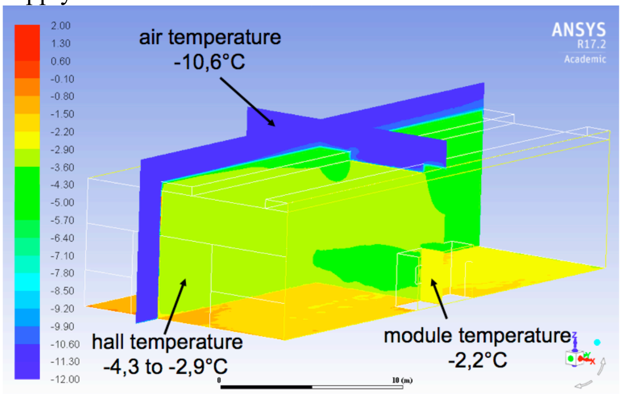

Figure 4: Winter scenario - hall temperature at 7.30 am

A first approximation can define the heating load simplified over the equation (4).

$$H = (\vartheta_i\text{-}\vartheta_a)*(H_T + L_V) \quad (4)$$

ϑ_i= standard interior temperature
ϑ_a= standard outdoor temperature
H_T= transmission heat losses
V_L = ventilation heat losses

Determinant for the reduced heat load is the difference between the internal and outside temperature. In Cologne, the standard outdoor temperature is -10°C and the interior temperature 20°C, in accordance with DIN EN 12831 supplement 2 table 2 for living- and bedrooms. The heat load is designed for a temperature difference ΔT with 30 kelvin.

If the outdoor temperature of -5°C, resulting out of the CFD-simulation, or the module temperature of -2,9°C taking the internal profits into consideration, will be chosen, the temperature difference decreases to 22,9 - 25 kelvin. That's why the heat load can be dimensioned 16-23% smaller and investment costs can be economised.

Especially the renewable heat supply is an intensive, heat supply, referred to the investment costs.

Heat pumps cost around 1300€/kW, so with a large number of modules a substantial cost reduction can be achieved. [10] The temperature of the hall is in all winter simulations at least 5 degrees above the outdoor temperature.

When the outdoor temperature will be set plus 5 kelvin as a reference temperature to calculate the heating demand the heating period duration will be reduced from 176 days to 117 days (weather profile location Lindenberg). In addition, the degree-day number decreases about 43% (from 3026 to 1713, by a heating threshold temperature of 10°C) and therefore diminish the heating demand about 43% towards the method according to EnEV.

6 Conclusion

A tool, optimised for "dre:RAUM" with regard to solar and internal gains, have been developed.

The absolute percentage points of the degree of self-sufficiency diverge 1,6% (version heat pump) to 5% (version solar thermal energy) from the reference value.

The CFD-simulation showed an excess of the comfortable insight module temperature, which should be between 25°C to 27°C, of 32°C. An additional simulation of the hours of over-temperature degree to determine the frequency of exceedance is considered as expedient.

In the winter scenario an additional heat source is required, since a living module temperature of merely -2,9 to -2,2°C is reached, despite the good insulation and internal heat source.

In this connection, a reduced heating load of maximum 16-23% could be calculated. For this reason, it is possible to design the regenerative heat supply smaller and to obtain investment costs up to 1300€/kW. Moreover, a reduction of the heating demand up to 43% towards the "normal" edge conditions have been calculated.

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