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# ENERGY DIAGNOSIS - A TECHNIQUE TO ASSESS RETROFITS IN RESIDENTIAL HOUSING

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## 1 Introduction

Today occupants, owners and administrations of residential buildings planning energy conserving retrofits are searching more than ever for qualified and independent advice. To be able to recommend suitable and economical retrofits for a specific building, the following principle investigations have to be performed. First the actual thermal state of the structure and the heating system has to be seized and analyzed. Then energy saving rates due to suitable retrofits have to be predicted and their economy to be judged. These procedures are combined by the technique Energy Diagnosis EDI (1). This method was tested investigating retroftis in 15 different buildings.

## 2 Description of the EDI - technique

The technique Energy Diagnosis EDI was developed to assess the actual thermal state of residential buildings, single-family and multi-family structures with less than 30 dwellings equipped with oil- or gasfired central heating systems, using standarized comprehensible criterions. For each inspected building it provides a choice of economic retrofits.

The EDI - technique covers the following basic procedures:

1. Collection of data to seize the actual state of the building and its heating system.

2. Preselection of possible retrofits analyzing the actual state and comparing to modern standards.

3. Evaluation of energy saving rates calculating the fuel demand in the actual state and after adopting retrofits individually or combined.

4. Estimation of the economy of individual retrofits and combinations of retrofits.

5. Arrangement of the results obtained by EDI and generation of recommendations to occupants, owners or administration of the building.

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To minimize the costs of this method, the EDI - technique is adjusted to computer processing.

## 2.1 Recording the actual state of building and heating system

To record the actual state of a specific building and its heating system, a simple method with low costs is applied. No time consuming and expensive measurements are involved.

The actual state of the structure and heating system is seized in situ by an unique inspection. During this procedure a trained inspector systematically identifies the different components of the structure and of the heating system. Characteristic parameters, which describe significant properties, performance and operating conditions of the heating system and of the structure, eg. surface of the boiler, insulation of the network, size of walls and windows, are transfered into questionaires.

Other parameters are taken from documents like construction plans or boiler check transcripts, which are enforced by law in the Federal Republic of Germany.

Parameters, which can't be seized, e.g. diameter of concealed pipes in the network, have to be assumed fitting to the present boundary conditons.

## 2.2 Analysis of the actual state and selection of retrofits

To select possible retrofits for a specific building the actual state of its components is analyzed using the collected data. Comparing them to modern technical standards, which are defined by law, guide lines and standard specifications, weak points can be detected.

For instance if the recorded data are displaying, that the installed boiler is poorly insulated (< 30 mm) or has high flue gas losses (> 10 %) or is strongly oversized (> 2,0) or is older than 10 years, the energy saving rate due to the retrofit "renewal of the boiler" is calculated and its economy is judged. Other retrofits are preselected in the same way.

With the EDI - technique energy conservation measures like renewal of the boiler, installation of supply temperature control, insulation of network, outer walls, roof etc. as well as combinations of these retrofits can be examined.

## 2.3 Evaluation of energy saving rates

The fuel consumption of the heating system in the actual state and after adopting selected retrofits is predicted by EDI taking climate, behaviour of the occupants and the characteristics of the structure and the heating system into account. This procedure is based on mathematical models of the components of the building and heating system under steady state conditions.



The heat demand of the building and the fuel consumption of the heating system is calculated respectively at two typical days of each month during the heating season. For that purpose the average outdoor temperature and average solar radiation of a typical clear and cloudy day of DIN 4710 (2) are used. On the base of the average duration of sunshine the frequency of these typical days is determined (3). In case the boiler is also preparing domestic hot water the fuel consumption is additionally evaluated at a typical average day in summer. Weighting the daily results the heat demand and fuel consumption per year are obtained.

The energy consumption of a heating system furthermore strongly depends on the behaviour of the occupants. Since the actual behaviour of the occupants can't be easily measured nor accurately inquired and in general is varying due to different influences, e.g. oscillating energy prices, fluctation of the occupants, three possible standard types of occupants with low, medium and high demand are defined (4). Their behaviour is expressed by daily hours of heating, temperature and air change rate in the rooms as well as demand of domestic hot water (table 1). Because these parameters are also influenced by the utilisation of the room, the building is devided into different heated and unheated zones.

| OCCUPANCY REQUIREMENTS | low | | | | medium | | | | high | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\tau_h$ (h/d) | $\vartheta_i$ ($^oC$) | $\beta$ (1/h) | $v_{dhw}$ (1/Pd) | $\tau_h$ (h/d) | $\vartheta_i$ ($^oC$) | $\beta$ (1/h) | $v_{dhw}$ (1/Pd) | $\tau_h$ (h/d) | $\vartheta_i$ ($^oC$) | $\beta$ (1/h) | $v_{dhw}$ (1/Pd) |
| living-room | 6 | 18 | 0,5 | | 15 | 20 | 1,0 | | 24 | 22 | 1,5 | |
| bedroom | 3 | 18 | 0,5 | | 11 | 18 | 1,0 | | 24 | 20 | 1,5 | |
| kitchen, bathroom | 6 | 20 | 1,0 | 20 | 15 | 20 | 1,5 | 50 | 24 | 22 | 2,0 | 80 |

Table 1: Definition of standarized occupancy behaviour

The daily heat demand of each heated zone is calculated at typical days assuming the standarized behaviour of the occupants. Internal and solar gains are considered (1).

$$Q_{\vartheta,z} = 24 \cdot \frac{\dot{Q}_{t,n} + \Delta\dot{Q}_n}{\bar{\vartheta}_{i,n} - \bar{\vartheta}_{o,n}} \cdot (\bar{\vartheta}_i - \bar{\vartheta}_o) + 24 \cdot \beta \cdot \varrho_a \cdot c_a \cdot (\bar{\vartheta}_i - \bar{\vartheta}_o)$$

$$- \eta_g \cdot (Q_{sol} + Q_{int}) \qquad (1)$$

The temperature $\bar{\vartheta}_i$ is the time averaged air temperature in the heated zone.

Calculating the fuel demand of the heating system it is assumed, that the heating system is operated satisfying the above defined occupancy requirements. Therefore e.g. the supply temperature is choosen according to room temperature, nominal performance of radiator and maximum heat loss of the room. The mass flows in the network are determined assuming ideal control. I.e. the network is exactly delivering the required heat demand of each heated zone.

[illegible] sation (5).

The energy demand of the network, which is identical to the useful energy of the boiler $Q_{\vartheta,b}$, is simply obtained by the relationship:

$$Q_{\vartheta,b} = \Sigma Q_{\vartheta,z} - \Sigma Q_{s,p} \qquad (2)$$

The last expression are the surface losses of the network, which cannot be utilized in the building. The surface losses of pipes on the surface and of concealed ducts are calculated using algorithms described in (1).

The daily fuel consumption of the boiler $Q_i$ is evaluated by the following energy balance (1):

$$Q_i = Q_{\vartheta,b} + (\dot{Q}_{fg} + \dot{Q}_{s,f}) \cdot \tau_f + (\dot{Q}_s + \dot{Q}_v).(24 - \tau_f) \qquad (3)$$

## 2.4 Estimation of economy

The economy of the investigated retrofits is judged caluculating the amount of capital, which has to be spend in a period of 10 years to maintain the actual state or to implement the investigated retrofits. Thereby investments, energy costs, remaining value and costs of replacement as well as interest rate and rise in prices are considered.

$$C = C_{in} + C_{en} - C_{rem} + C_{repl} \qquad (4)$$

The most economical measure has the lowest total value of capital.

# 3 Application of the EDI - technique to a double-family building

In the following results obtained applying the EDI - technique to a double-family building are outlined. Analyzing the actual state of this building and its heating system, the following retrofits are choosen exemplary to be examined in detail:

- Retrofit A: Renewal of the boiler
- Retrofit B: Insulation of outer walls
- Retrofit C: Insulation of outer walls and renewal of the boiler.



All retrofits include the installation of supply temperature control.

Calculating the energy consumption in the actual state of the structure and the heating system and after implementation of the selected retrofits characteristic curves - energy consumption of the heating system versus heat demand of the building - are obtained (figure 1). They respectively describe the thermal state of the structure and the heating system taking different behaviour of the occupants into account. The heat demand of the building includes the heat demand of the heated zones and the demand of domestic hot water [illegible] rates due to the selected retrofits. Moreover it displays, how energy consumption as well as energy saving rates are influenced by the behaviour of the occupants.

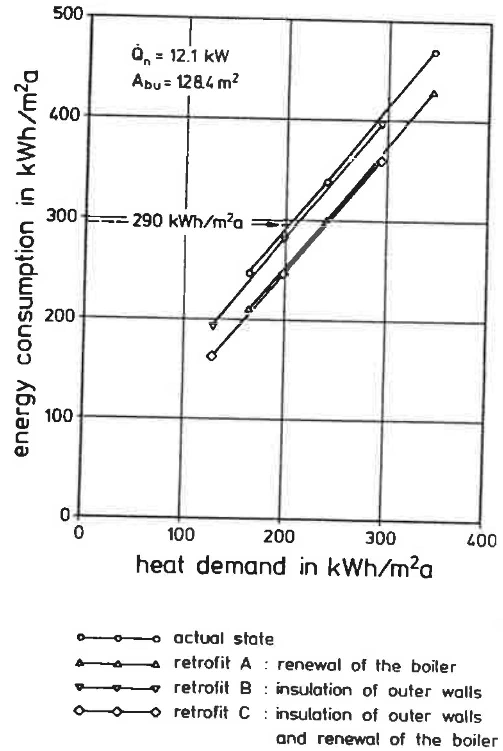
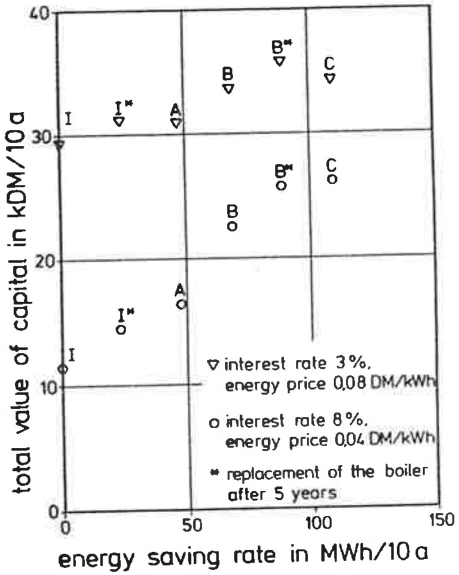



Figure 1: Energy consumption of the boiler and heat demand of the building related to heated area in the actual state and after adopting retrofits

To determine energy saving rates in a specific building considering the real occupancy behaviour, the average behaviour of these occupants is estimated using the average fuel consumption of the last five years.

The average fuel consumption of the double-family building amounts to about 290 kWh/m²a, i.e. the average requirements of the occupants are low to medium. Now the energy consumption, which can be exspected in this building due to the investigated retrofits, is derived from figure 1.

The energy saving rates and the total value of capital in the actual state and due to the inspected conservation measures are shown in figure 2. A period of 10 years and two different combinations of interest rate and energy price are considered. Since the installed boiler is 15 years old, the replacement of the boiler after 5 years (signed with *) is also investigated.




I : actual state
retrofit A : renewal of the boiler
retrofit B : insulation of outer walls
retrofit C : insulation of outer walls and renewal of the boiler

Figure 2: Total value of capital and energy saving rate in the actual state and due to retrofits in a period of 10 years (rise in prices 3 %)



Regarding high interest rate and low energy price, retaining the actual state or replacing the boiler after 5 years are the most economic measures. Insulation of the building (with or without renewal of the boiler) requires almost double expenses despite high energy saving rates.

Under the boundary conditions of low interest rate and high energy price the total value of capital due to each investigated measure increases. However the range among them strongly reduces, i.e. all measures are close to economical level. Retaining the actual state is still most economic. But with respect to reliability of the heating system the immidiate renewal of the boiler is recommended. Insulation of the structure combined with the renewal of the boiler might be suggested, if the facade is planned to be renovated before long. In this case the total value of capital reduces almost to the level of the actual state.

## 4 Conclusions

The EDI - technique can be used to assess energy conserving measures implemented in residential buildings with oil- and gasfired central heating systems. Using significant data collected in situ the actual state of the structure and heating system is analyzed. Energy saving rates due to different retrofits are calculated taking the dominant influences into account. Their economy is judged. Based on these fundamental investigations qualified and neutral recommendations are provided to owners, occupants or administration of the inspected building. Furthermore applying the results of EDI energy consultation and planning can be offered by engineers, architects as well as companies accomplishing retrofits.

## Reference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## Nomenclature

Parameters and variables:

| symbol | unit | term |
|---|---|---|
| $A$ | $m^2$ | area |
| $C$ | DM | value of capital |
| $c$ | $J\ kg^{-1}\ K^{-1}$ | specific heat capacity |
| $Q_i$ | J | fuel consumption |
| $Q_{int}$ | J | internal heat gains |
| $Q_{sol}$ | J | solar heat gains |
| $Q_{\vartheta,b}$ | J | useful energy of the boiler |
| $Q_{\vartheta}$ | J | heat demand of the building |
| $\dot{Q}$ | W | heat flow, heat loss |
| $\dot{Q}_n$ | W | nominal heat load of the building |
| $\Delta\dot{Q}_n$ | W | nominal heat load due to heat bridges |
| $v_{dhw}$ | $l\ P^{-1}\ d^{-1}$ | demand of domestic hot water per person |
| $\beta$ | $h^{-1}$ | air change rate |
| $\vartheta$ | $^{o}C$ | temperature |
| $\vartheta$ | - | degree of energy utilisation |
| $\rho$ | $kg\ m^{-3}$ | density |
| $\tau_f$ | h | operating time of the furnace |
| $\tau_h$ | h | duration of heating |

Indices:

| | |
|---|---|
| a | air |
| b | boiler |
| bu | building |
| en | energy |
| f | furnace |
| fg | flue gas |
| g | heat gains |
| i | indoor |
| in | investment |
| o | outdoor |
| p | pipe |
| rem | remaining value |
| repl | replacement |
| s | surface |
| t | transmission |
| z | zone |