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# Energy Performance Comparison of Decentralized vs. Centralized Mechanical Ventilation Systems

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## Abstract

*Ventilation in buildings is extremely important to create a healthy environment and prevent mold growth. The new building regulations demand an air - tight building envelope in order to improve its energy efficiency. Therefore, infiltrations and natural ventilation are often not sufficient to provide an adequate air change and mechanical ventilation becomes necessary.*

*The main goal of this study is to evaluate the energy demand of a decentralized ventilation system with respect to a centralized ventilation system in a typical residential building using dynamic simulation in Trnsys environment. German and Italian climate conditions as well as building insulation values of both countries were considered. Ventilation flow rates are according to the European Standards. Occupancy patterns were assumed for each room.*

*The results indicate that in colder climate the energy demand for heating and cooling does not change sensibly with the two configurations, while the centralized system has an electric energy consumption 50 to 70 percent greater than the decentralized system. In warmer climates, the former system requires nearly 30 percent more energy for heating and 30 percent less for cooling than the latter system. Primary energy consumption is always less with the decentralized system. This is due mainly to the greater amount of air processed by the centralized system in order to provide the requested air quality in each room. Although the decentralized system seems to require less energy, other factors (e.g., installation and O&M costs) could influence the convenience of this configuration.*

**Keywords – mechanical ventilation; decentralized ventilation; Trnsys**

## 1. Introduction

Buildings in the European Union (EU) account for 40% of the EU's total final energy consumption and are responsible for about one third of

global CO<sub>2</sub> emissions [1]. By and large, heating, cooling and ventilation systems represent the majority of energy consumption of buildings, accounting for half the energy use [2]. A study [3] about the energy impact of ventilation and air infiltration in residential buildings in 13 countries shows that the energy losses due to ventilation and air infiltration represent about 48% of the energy delivered for space heating.

Retrofitting of existing buildings offers a great opportunity for reducing energy consumption and greenhouse gas emissions. The first retrofit alternatives to be considered for existing residential buildings are improvement of the thermal insulation and air tightness.

As until the 1990s buildings were designed with natural ventilation, they become airtight buildings after renovation and the air infiltration rate is often not sufficient to maintain acceptable indoor air quality. Indoor air quality is greatly influenced by the amount of fresh air that enters the building. A good solution in such buildings is mechanical ventilation with heat recovery to recover the heat from exhaust air and, in such way, to reduce the ventilation heat losses.

Developing more and more efficient ventilation techniques is a key issue, in the design of new “low” (and “zero”) energy buildings, as well as in the retrofit of existing ones.

## **2. The Model**

A typical German dwelling designed for four people is considered in this work. The building is a single-family detached home and it consists of two stories. In the ground floor, there are a kitchen, a guestroom, a living room, a toilet and a corridor. In the first floor, there are two children’s bedrooms, one parent’s bedroom, one bathroom and a corridor. Over the first floor, there is an uninhabitable attic. Each room, included the attic, is considered as a thermal zone with a single air node, so the model counts 11 thermal zones. Each story has a floor surface of 69.1 m<sup>2</sup>, for a total net floor surface of 138.2 m<sup>2</sup>. The total volume of the dwelling is 329.1 m<sup>3</sup>. Visual interface TRNBuild is used to model the building.

Two different building envelopes are considered, i.e., different U-values for the surfaces. The first one is according to the German standard EnEV 2013 (Energieeinsparverordnung) [4] values of thermal transmittance for opaque and glazed surfaces, while the second one is according to Appendix B, Annex 1 of the Italian D.M. 26 giugno 2015 “Requisiti minimi” [5], for the climate zone B. However, beside the different thermal transmittance values, the same building is considered, i.e., layout of the rooms, heat gains, ventilation and thermal plants are the same in all simulations.

The heating system has a set point temperature of 20°C and it has unlimited power with 30% radiative part and without humidification. The cooling system has a set point temperature of 26°C and it has unlimited power with dehumidification. Since cooling systems are not common in

German dwellings, both cases are considered, with and without cooling devices.

The internal heat gains per year due to lighting, electrical appliances and people are 4255.4 kWh, or 30.8 kWh/m<sup>2</sup>. Shading reduction factors are considered to calculate the contribution of solar radiation in terms of heat gains and to control the artificial lighting in the building.

According to the ASHRAE Handbook [6](ASHRAE, 2011), the infiltration rate is assigned as 0.1 h<sup>-1</sup>.

Different occupancy patterns for each room are considered, according to a previous study on the same residential building [7](Zwiehoff, 2013) and a study from the literature [8](Martinaitis V., 2015).

The model is realized in Trnsys environment.

## 1. The Ventilation Systems

The European standard EN 15251 [9] is used to calculate the recommended design ventilation rates in the residential building.

Two different configurations of mechanical ventilation systems are considered and compared. Those are centralized and decentralized ventilation systems with heat recovery. Both systems are balanced. Two cities are considered, in order to compare two different climate conditions and typical building characteristics, in terms of level of insulation. The first city is Stuttgart, Germany; the second one is Palermo, Italy. The weather data are taken from the EnergyPlus database.

In decentralized ventilation simulations, each room is considered independent from the others and airtight, unless the infiltration flow rate equal to 0.1 h<sup>-1</sup>. In centralized ventilation mode, an air flow is assumed to pass from the rooms in which the fresh air is supplied to those in which the air is extracted. An air coupling flow rate is calculated for each room, according to the supply and extract flow rates. The air is supplied in the living room, in the guest room and in the three bedrooms. The air extractors are localized in the kitchen, in the toilet and in the bathroom.

The centralized ventilation system is composed by an air handling unit (supply and extractor fans, heat recovery, auxiliary heater, filters), an inlet duct system from outside with silencer and wall terminal, an outlet duct system toward outside with silencer and wall terminal, a supply distribution duct system to main rooms and an exhaust duct system from wet rooms.

Airflow rates are calculated according to the standard DIN EN 15251:2012. The supply ventilation airflow rate  $Q_s = 273.1$  kg/h is chosen as nominal airflow rate in occupied periods, in order to provide the nominal airflow rates in each main room. During unoccupied period, i.e., when nobody is in the building, a minimum airflow rate  $Q_u$  of 0.1 l/s·m<sup>2</sup> is considered according to total floor area:

$$Q_u = 0.1 \text{ l/(s} \cdot \text{m}^2) \cdot 138.2 \text{ m}^2 = 13.8 \text{ l/s} = 59.9 \text{ kg/h} \quad (1)$$

The total exhaust airflow rate is assumed equal to the supply airflow rate and this value is weighted on rooms' volume.

Considering the disposition of rooms, a duct system is modeled in order to calculate the pressure losses.

According to the results of calculations, the pressure heads of the supply and exhaust duct systems are respectively of 48.7 Pa and 30.8 Pa. The pressure drops due to filters and heat recovery are both assumed equal to 110 Pa.

Therefore, the total  $\Delta p$  of supply and extract fans are respectively of 258.7 Pa and 240.8 Pa.

According to the "Recommendations for calculation of energy consumption of air handling unit" (Eurovent, 2005) [10], the electrical power consumption of fans is calculated with the following formula:

$$P_{el} = (\dot{m} \cdot \Delta p_{fan}) / (\eta_{vent} \cdot 1000) \quad (2)$$

Where:

$P_{el}$  = electrical power in kW;

$\dot{m}$  = airflow rate in m<sup>3</sup>/s;

$\Delta p_{fan}$  = pressure head of the fan for the corresponding flow rate in Pa;

$\eta_{vent}$  = ventilation efficiency (motor fan's efficiency and ventilation losses).

The actual pressure drop is calculated with the following formula:

$$\Delta p_{fan} = \eta_{vent} \cdot \Delta p_{fan,nom} \cdot \dot{m}_{max}^2 \quad (3)$$

Where:

$\Delta p_{fan,nom}$  = nominal pressure drop in Pa;

$\dot{m}$  = actual flow rate in kg/h;

$\dot{m}_{max}$  = nominal flow rate in kg/h.

The heat recovery (Type 760a) models the heat exchange between the fresh air from outside and the exhaust air from rooms. It is supposed to operate in counter flow with sensible effectiveness equal to 0.8, according to the actual market (CasaClima, 2015) [11]. A control signal is used to switch the heat recovery in on/off mode. Mode On is set when the following conditions are achieved:

$$\{[(T_{ext} < 20) \cup (T_{ext} > T_{room})] \cap (T_{room} < 26)\} \cup \{[(T_{ext} < 15) \cup (T_{ext} > T_{room})] \cap (T_{room} > 26)\} \quad (4)$$

Where:

$T_{ext}$  = external temperature in °C;

$T_{room}$  = temperature of the room in °C.

The conditions of the exhaust air are calculated by mixing the extract flow rates from wet rooms. The auxiliary heater (Type 6) goes in operation when the temperature of the fresh air reach 0°C, in order to prevent frost.

The decentralized ventilation system is composed of exhaust and supply fans, heat recovery, auxiliary heater and filters. One device is installed in each room in which air change is required, i.e., every room but corridors. In the building considered in this work the total number of devices is eight. Each single unit functions fully by itself and can be individually controlled. They are mounted onto the façade and do not include long ventilation ducts. The airflow rates are determined according to EN 15251:2007. During occupied periods, the flow rate is calculated as follows:

$$Q_{dec,occ}=7 \cdot N_p \quad (5)$$

Where:

$Q_{dec,occ}$  = airflow rate during occupied periods in l/s;

7 = airflow rate per person recommended by the norm in l/(s·pers);

$N_p$  = number of people in the room.

Assuming a density of the air of  $\rho_{air} = 1.204 \text{ kg/m}^3$ , the flow rate per person is equal to 30.34 kg/(h·pers).

During unoccupied periods, the minimum flow rate is determined according to floor area and it is equal to 0.43 kg/(h·m<sup>2</sup>).

The two fans are modeled with the following formulae:

$$W=(\Delta p \cdot \dot{m})/(\rho_a \cdot \eta_{vent}) \quad (6)$$

Where:

W = electrical power consumption of the considered fan in Watt;

$\Delta p$  = pressure drop of the considered fan in Pa;

$\dot{m}$  = airflow rate in kg/s;

$\rho_a$  = density of the air in kg/m<sup>3</sup>;

$\eta_{vent}$  = ventilation efficiency of the fans, assumed to be equal to 0.7.

$$\Delta p=0.3 \cdot \Delta p_{max}+0.7 \cdot \Delta p_{max} (\dot{m}/\dot{m}_{max}^2) \quad (7)$$

Where:

$\Delta p_{max}$  = maximum pressure drop of the considered fan, due to heat recovery, filter, grills, and assumed to be equal to 260 Pa;

$\dot{m}_{max}$  = maximum flow rate assumed to be equal to 120.4 kg/h.

As well as the centralized ventilation system, sensible effectiveness of the heat recovery is assumed to be equal to 0.8 as a mean value of the actual market (CasaClima, 2015). The auxiliary heater has a set point of 0°C.

The centralized ventilation system considered in this work has two airflow rate levels, minimum and nominal, respectively of 49.8 m<sup>3</sup>/h and

226.8 m<sup>3</sup>/h. The minimum airflow rate is used when nobody is in the dwelling with the purpose of ensuring adequate air change to the building, e.g., to avoid condensation-related problems, such as mold growth. The nominal airflow rate is used when at least one person is in the building, since a regulation on the distribution terminals would unbalance the flow rate in the rooms.

The decentralized devices have different levels of airflow rate, they are each one independent from the others and room-based. When nobody is in the room, the minimum airflow rate ( $0.1 \text{ l}/(\text{s}\cdot\text{m}^2)\cdot A_{f,\text{room}}$ ) according to floor area  $A_{f,\text{room}}$  is supplied to the considered room. Otherwise, airflow rate according to number of people  $N_P$  the room ( $7 \text{ l}/(\text{s}\cdot\text{pers})\cdot N_P$ ) is provided.

The presence of people can be detected by CO<sub>2</sub> sensors installed in each room where a ventilation device is set up. CO<sub>2</sub> concentration is proportional to the number of people in the room. According to the standard EN 13779:2007 [12], the default CO<sub>2</sub> emission rate is equal to 20 l/(h·pers).

## 2. Results

### 2.1 Case 1

In the first simulation, the following conditions are considered:

- Stuttgart
- Heat recovery
- Cooling system
- German building

Figure 2.1 and Figure 2.2 show the heating and cooling demand (sensible and latent) all over the year, respectively for centralized and decentralized ventilation systems.

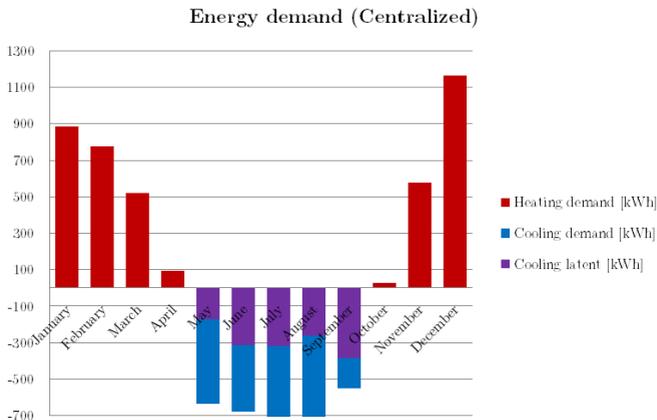


Fig. 2.1 Energy demand with centralized ventilation system.

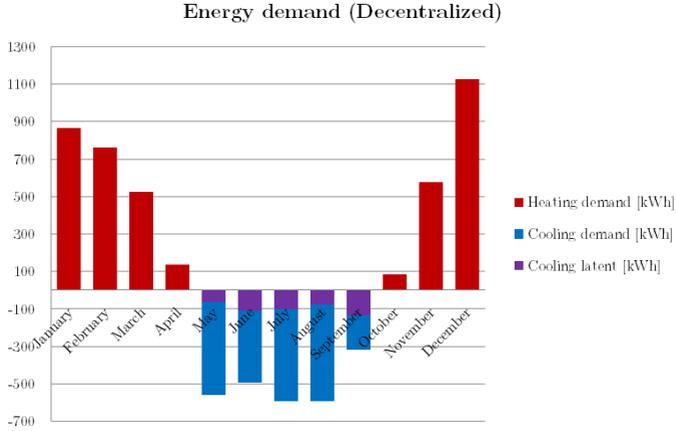


Fig. 2.2 Energy demand with decentralized ventilation system.

The heating demand is mostly the same for the two configurations. Sensible cooling demand is slightly less with the centralized system, while latent cooling demand is less with the decentralized system. The decentralized system absorbs 56% less power than the centralized, because the latter is in operation for a higher number of hours. For the same reason, the heat recovered with centralized system is 46% more than that with decentralized system. In order to achieve a better comparison of the two systems, the primary energy demands (EP) in kWh are calculated with the following formula:

$$EP = W_e \cdot f_{p,e} + (Q_H / \eta_g) \cdot f_{p,t} + (Q_C / SEER) \cdot f_{p,e} \quad (8)$$

Where:

$W_e$  = electrical consumptions of the ventilation system in kWh;

$f_{p,e}$  = primary energy factor for electricity, assumed equal to 2.2;

$Q_H$  = energy demand for heating in kWh;

$\eta_g$  = generation efficiency of the heating system, assumed equal to 0.9;

$f_{p,t}$  = primary energy factor for thermal energy, assumed equal to 1.05;

$Q_C$  = energy demand for cooling in kWh;

SEER = Seasonal Energy Efficiency Ratio, assumed equal to 3.

For the centralized system, EP = 7171.1 kWh; for the decentralized system, EP = 6693.4 kWh.

## 2.2 Case 2

In the second simulation, the following conditions are considered:

- Stuttgart
- No heat recovery

- Cooling system
- German building

In this configuration, the heating and cooling (sensible) demands with decentralized ventilation system are respectively 24% less and 23% more than with centralized system; latent demand for cooling is 75% less. Since the centralized system could recover more heat, because it is more in operation, the decentralized system becomes more competitive without heat recovery. The electrical consumptions are the same of the previous case. Primary energy demand for centralized and decentralized system, calculated using Equation 8, are respectively  $EP_c = 10444.8$  kWh and  $EP_d = 8121.5$  kWh.

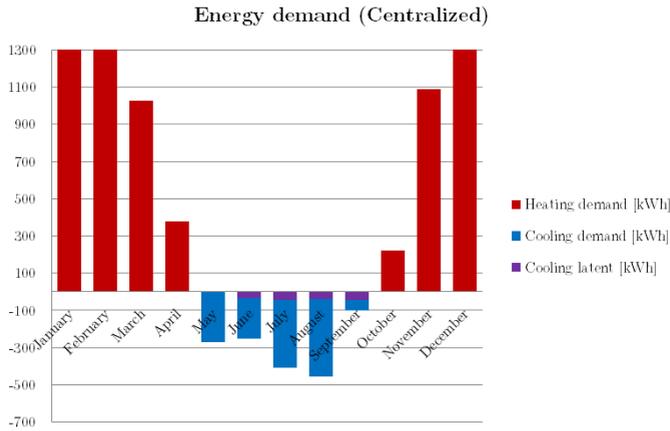


Fig. 2.3 Energy demand with centralized ventilation system.

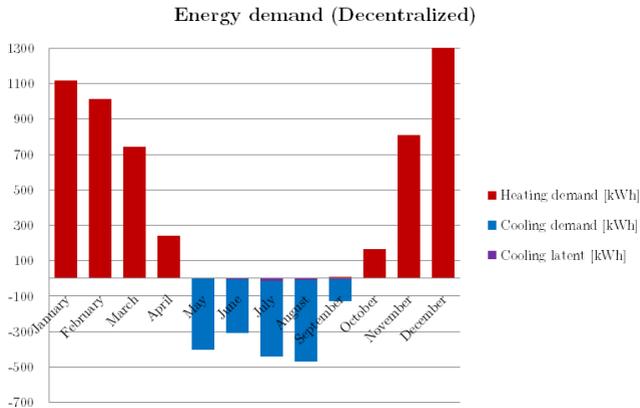


Fig. 2.4 Energy demand with decentralized ventilation system.

### **2.3 Case 3**

In the third simulation, the following conditions are considered:

- Stuttgart
- Heat recovery
- No cooling system
- German building

In this configuration, the heating demands with decentralized and centralized ventilation systems are similar, respectively equal to 4191 kWh and 4138 kWh, like the first case. The reason for this has to be search in the airflow rates: in a specific period, the centralized system elaborates more air and so recovers more heat; conversely, the decentralized system elaborates less air saving energy from ventilation losses. The electrical consumptions are very similar to the previous case. Primary energy demand for centralized and decentralized system are respectively  $E_{Pc} = 5782.5$  kWh and  $E_{Pd} = 5308.4$  kWh.

### **2.4 Case 4**

In the fourth simulation, the following conditions are considered:

- Stuttgart
- No heat recovery
- No cooling system
- German building

In this configuration, with the decentralized ventilation system the heating demand is 24% less than with centralized system; the electrical consumption is 56% less. Primary energy demand for centralized and decentralized system are respectively  $E_{Pc} = 9442.2$  kWh and  $E_{Pd} = 6821.6$  kWh.

### **4.5 Case 5**

In the fifth simulation, the following conditions are considered:

- Palermo
- Heat recovery
- Cooling system
- Italian building

In this configuration, with the decentralized ventilation system the heating demand is 28% more than with centralized system; the sensible and latent cooling demand are respectively 9% less and 67% less. The electrical consumptions with the decentralized system are 74% less. Conversely, the centralized system recovers 42% more heat. Primary energy demand for centralized and decentralized system are respectively  $E_{Pc} = 4244.3$  kWh and  $E_{Pd} = 3932.6$  kWh.

#### **4.6 Case 6**

In the sixth simulation, the following conditions are considered:

- Palermo
- No heat recovery
- Cooling system
- Italian building

In this configuration, the heating demand is 9% less with decentralized system, the cooling demand is 8% less (sensible) and 66% less (latent). The electrical consumption is 74% less with decentralized system. Primary energy demand for centralized and decentralized system are respectively  $EP_c = 5168.3$  kWh and  $EP_d = 4298.2$  kWh.

#### **4.7 Case 7**

In the seventh simulation, the following conditions are considered:

- Palermo
- Heat recovery
- Cooling system
- German building

In this configuration, the heating demand is 85% more with decentralized ventilation system; the sensible and latent cooling demands are respectively 12% less and 70% less. The electrical consumption is 46% less than with centralized system. Primary energy demand for centralized and decentralized system are respectively  $EP_c = 3878.8$  kWh and  $EP_d = 3057.7$  kWh.

#### **4.8 Case 8**

In the eighth simulation, the following conditions are considered:

- Palermo
- No heat recovery
- Cooling system
- German building

In this configuration, the heating demand with decentralized ventilation system is 62% more than with centralized system; the cooling demand is 9% less (sensible) and 65% less (latent). The electrical consumption is 74% less with decentralized system. Primary energy demand for centralized and decentralized system are respectively  $EP_c = 3741.9$  kWh and  $EP_d = 3115.2$  kWh.

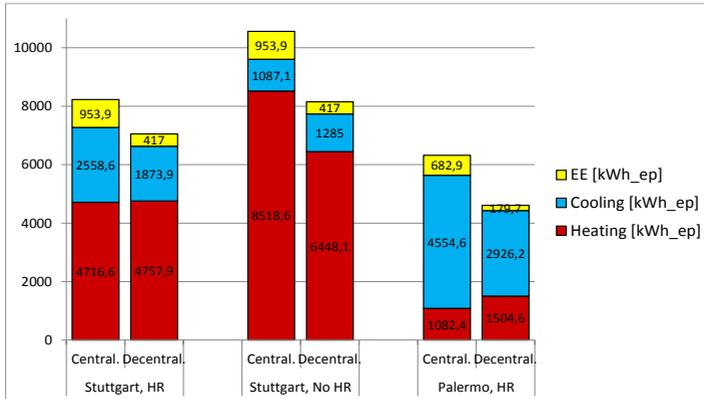


Fig. 2.5 Comparison of Primary Energy consumptions.

### 3. Conclusions

Two different mechanical ventilation systems, centralized and decentralized, were considered in this work, in order to compare the energy performance. A typical German dwelling with climate conditions of Stuttgart and Palermo was modeled in Trnsys environment. The following results of different case of studies were presented:

- The centralized system requires higher airflow rates, in order to supply the design airflows in each room. Therefore, it recovers more energy than the decentralized system, but the former is more ‘energivorous’.
- In colder climate with heat recovery, the energy demand for heating and sensible cooling does not change sensibly in the two configurations. Energy demand for latent cooling and electrical consumption (fans and auxiliary heaters) are sensibly lower in decentralized system.
- In colder climate without heat recovery, lower energy demand for heating, latent cooling and electrical consumption is required with decentralized system. However, it requires higher energy demand for sensible cooling.
- In warmer climate, the decentralized system requires more energy for heating and less for cooling and electrical consumption with respect to the centralized system.

The decentralized ventilation system appears to be more convenient in terms of energy demand for heating and cooling than the centralized system in most of the cases, since the latter has to supply an higher airflow rate to provide the design airflow in each room. However, other factors (e.g., installation and O&M costs) could influence the convenience of this configuration. This issue could be an interesting continuation of this work.

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