LCA on HFC-365mfc and high performance rigid polyurethane foams

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The motivation for this study

Adequate temperatures in our working and living spaces keep as healthy and are a part of our living comfort that we do not want to miss. On the other hand, efficient housekeeping with natural resources as well as avoiding unacceptable overloads of our environment with emissions and waste have become an ever increasing demand during the last decades. Therefore, we are challenged to find solutions which satisfy our needs and at the same time prove to be environmentally responsible and economically viable.

Thermal insulation can contribute significantly to reach these goals, PU-rigid foams being amongst the most efficient thermal insulation materials known so far.

Halogenated hydrocarbons have proven to be the most effective blowing agents in terms of achievable insulation performance of PU-rigid foam products. However, the use of fully halogenated (first generation) chlorofluoro-hydrocarbon (CFC) blowing agents like R11 had to be stopped because of the high ozone depletion potential (ODP) of such compounds. Partially halogenated (second generation) hydrochlorofluoro-carbon (HCFC) blowing agents like 141b – even though > 90 % reduction of the ODP as compared to R11 was achieved – have to be withdrawn from the markets in the EU, USA, and Japan between 2003 and 2004.

Third generation hydrofluorocarbons (HFC) like 365mfc (1,1,1,3,3-pentafluorobutane), which do not affect the ozone layer at all, are at present developed to fill the gap of high-performing blowing agents.

Reflecting the importance of environmental aspects, it is obvious that insulation products manufactured by using third generation blowing agents have to prove their environmental competitiveness to achieve market acceptance. In this context information is required for the dialog with all stake holders as well as to support company internal decision making.

Therefore, Solvay Fluor und Derivate decided to commission this life cycle assessment (LCA) to support the application development and the market positioning of 365mfc as a blowing agent for PU-rigid foams. Elastogran, Kingspan and Synthesia as experts and stake holders in the PU-industry were invited and accepted to join the project as partners.

The goals of the study

The project partners jointly agreed upon the following goals of the study:

Elaborate a full LCA (complete insulation systems, comprising all relevant environmental aspects – no restriction to single selection criteria) comparing different blowing agents in selected PU-rigid foam insulation products to support

- application development of 365mfc-blown PU-rigid foam products
- positioning of 365mfc-blown PU-rigid foam products on the market.

The acceptance of the study is regarded as a key issue. Therefore the study is performed

(a) in collaboration with partners who participate in the production chain of thermal insulation and
(b) according to the respective ISO-standards (ISO EN 14040 series) including an external critical review.

The results of the study are published in a full report as well as in a summary report available from any of the project partners.

The scope of the study

The PU-rigid foam thermal insulation products under study are

- 141b-, water/CO_2-, 365mfc-blown sprays for a warm flat roof of an industry building
- 141b-, n-pentane, 365mfc-blown boards for cavity walls and warm pitched roofs of domestic houses.

The functional unit for the investigations is 1 m^2 of insulated area with PU-rigid foam products of specific thicknesses. The system boundaries of the study encompass the complete life cycle of the products; recycling/disposal options are dealt with separately, however. Investigations refer to the situation in Germany and to current technologies.

The impact assessment is performed regarding those environmental categories which are considered particularly relevant for sustainable development today and for the product systems investigated, i.e. cumulative energy demand, requirement of non regenerative (non-fuel) material resources, water demand, global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), nutrification potential (NP), photochemical ozone creation potential (POCP), potentially hazardous and non-hazardous waste.

Key settings for standard scenarios are given in the table below.

	sprays	**boards**
spec. weight [kg/m^3]	60	32
facing	no facing	alu-foil/kraft paper/alu-foil (7μm each) on both sides
foam thickness [m]	roof: 0.04	roof: 0.1 wall: 0.05
λ-value [mW/(m*K)]	141b: 29 H_2O/CO_2 35 365mfc: 30	141b: 21 n-pentane: 24 365mfc: 22
blowing agent emissions during production [%]	15	5
service life for calculation [years]	25	50
blowing agent emissions during service life [% or %/a]	1st year: 5, following years: 1.2	0.2
degree days [K*d/a]	2717	3500
heating system	oil heating	Mix 2000 (Germany)

The key settings for standard scenarios vary throughout Europe, e.g. in Spain sprays are used with lower density (45 kg/m^3) or different facings for boards (50 µm aluminium foil instead of tri-laminate facings) are applied in different countries.

In addition to calculating standard scenarios, sensitivity analyses are performed for all aspects and settings which may influence the results of the study, i.e. service life, degree days, thermal conductivity of PU-rigid foams, diffusion rate of blowing agents during service life, thickness of the PU-rigid foams, heating systems and allocations of inputs and outputs for production steps which give raise to more than one product.

The Results

General findings

Regarding the complete life-cycle of the PU-rigid foam sprays and boards investigated, the use phase of the products clearly dominates all environmental criteria investigated with the exception of the parameter water demand. Thus, the production of the products itself is only of marginal importance (figure 1and 2), with the exception of water demand and NP (some products) and ODP (only 141b-blown products).

During the use phase the environmental effects resulting directly or indirectly (e.g. acquisition of fuels) from necessary heating to compensate thermal losses determine most of the environmental aspects investigated by at least 75 % and up to 99 %.

Blowing agent losses during the use phase contribute only to a limited extend to GWP (141b and 365mfc: 1 – 7 %) and POCP (n-pentane: 1 – 2 %). As expected losses of 141b during production of foams and during the use phase of such products determine the ODP – all other product systems show only very low ODP-values due to unspecified emissions e.g. from power plants.

The contribution to the overall environmental profiles caused by the recycling/disposal of PU-rigid foam sprays and boards was found to be marginal (2 % or less) when considering waste incineration with energy recovery (which completely destroys blowing agents still present in the foams). Otherwise blowing agents emitted in the course of recycling/disposal may substantially worsen the environmental performance particularly regarding 141b- (for ODP and for GWP), 365mfc- (for GWP), and n-pentane- (for POCP) blown products.

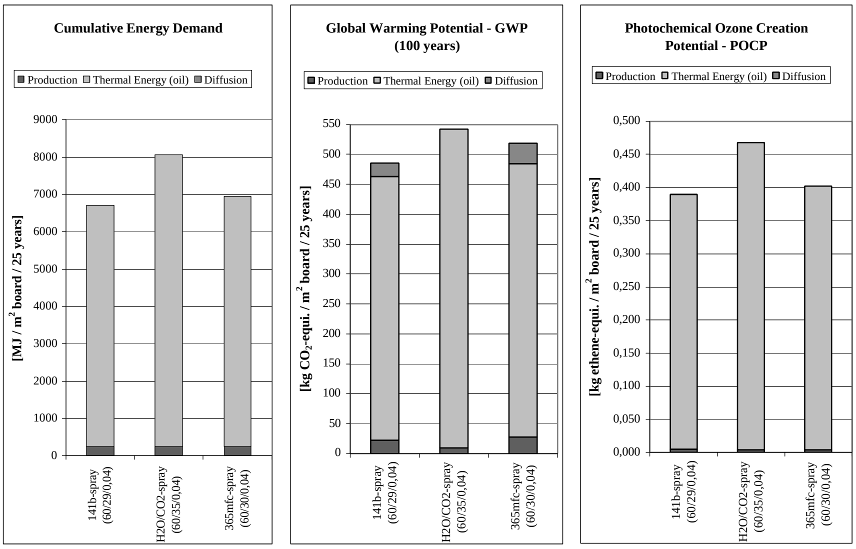

Figure 1: Cumulative energy demand, GWP , and POCP for thermal insulation systems with different PU-rigid foam sprays

Shown are standard scenarios for sprays without facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)], and the thickness in [m]. For key settings see preceding table.

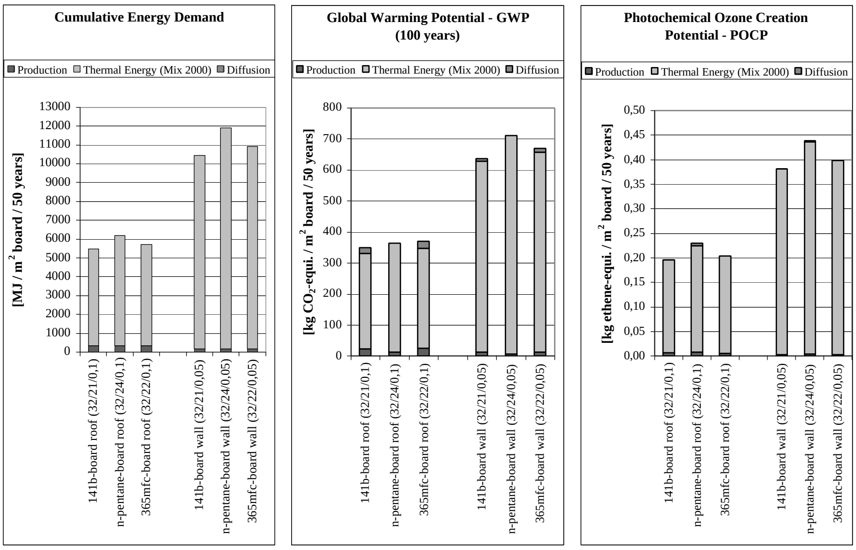

Figure 2: Cumulative energy demand, GWP , and POCP for thermal insulation systems with different PU-rigid foam boards

Shown are standard scenarios for boards with tri-laminate facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)], and the thickness in [m]. For key settings see preceding table.

<u>Comparison of PU-rigid foam sprays for the thermal insulation of a flat warm roof</u>

In the standard scenario (figure 1) the 365mfc-blown spray shows an app. 4 % lower GWP and approx. 15 % lower values for all other criteria as compared to the water/CO_2-blown spray. As compared to the 141b-blown spray the 365mfc-blown spray is found to cause marginally higher (2 – 6 %) environmental effects, avoiding however the 141b-born ODP.

Sensitivity analyses reveal:

- The environmental advantages of the 365mfc-blown spray increases in absolute terms when increasing the service life of the products or under conditions requiring more heating.
- Assuming an increase in blowing agent losses during the service live of the sprays will only affect the parameters GWP, ODP and POCP (i.e. the advantages of the 365mfc-blown product for the other parameters remain valid). 365mfc-losses of approx. 2.5 %/a would result in a total GWP that equals the respective value for the water/CO_2-blown spray (figure 3); such losses however exceed empirical values.
- Increasing the thickness equally for all sprays will not substantially alter the results except for the GWP for which the reduction of heating generated CO_2 is counterbalanced by GWP relevant

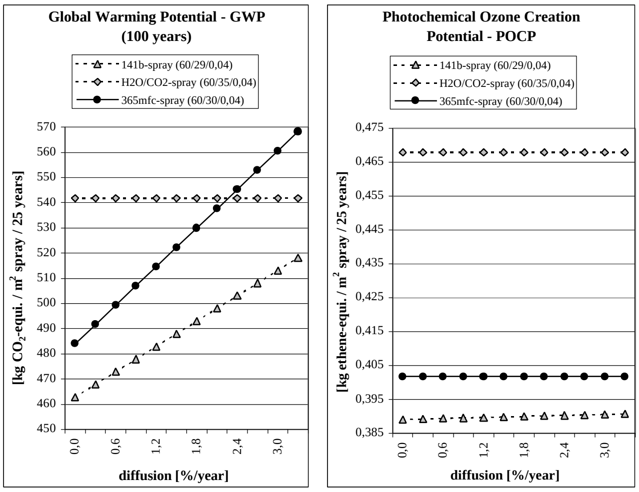

Figure 3: Dependence of the GWP and POCP on variations in the diffusion rates of different PU-rigid foam sprays
Shown are standard scenarios with varying diffusions rates of blowing agent for sprays without facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)], and the thickness in [m]. For key settings see preceding table.

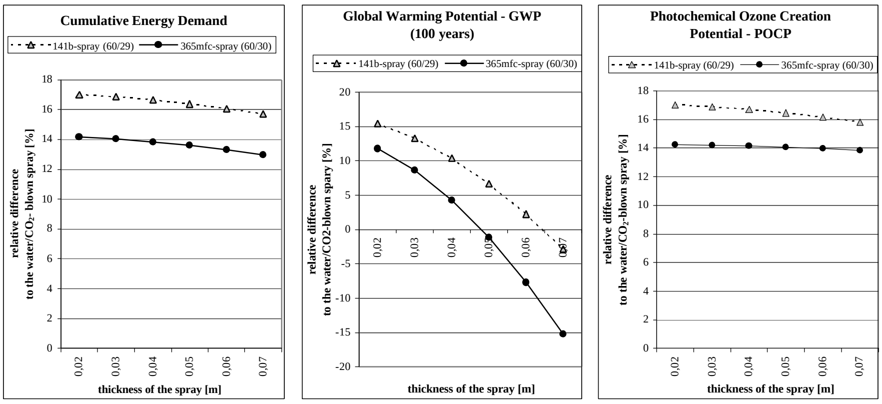

Figure 4: Dependence of the cumulative energy demand, GWP and POCP on variations in the thickness of 365mfc- and 141b-blown PU-rigid foam sprays relative to the water/CO_2-blown spray
Shown are standard scenarios with varying thicknesses for sprays without facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)]. For key settings see preceding table. Positive values represent environmental advantages while negative values stand for environmental disadvantages.

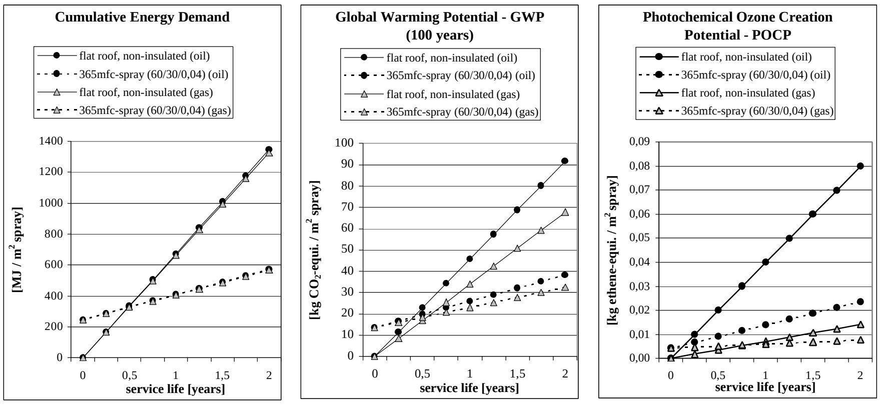

Figure 5: Cumulative energy demand, GWP, and POCP for a non-insulated and an with a 365mfc-blown spray insulated flat warm roof with different heating systems during the first two years of use
Shown are standard scenarios for different heating systems for sprays without facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)]. The source for the thermal energy is either a central oil or gas heating system. For key settings see preceding table.

emissions of blowing agents. Below a thickness of approx. 0.05 m the 365mfc-blown spray shows a lower GWP as compared to the water/CO_2-blown spray. Above this break-even point the 365mfc-blown spray shows a higher GWP as compared to the water/CO_2-blown spray, keeping however its environmental advantages in the other parameters (figure 4).

- To achieve the insulation performance of the 365mfc-blown spray the thickness of a water/CO_2-blown spray has to be increased by approx. 17 %.

For u-values higher than 0.8 W/(m^2 * K) the GWPs for all thermal insulation systems regarded are equally competitive (i.e. differences are below approx. 10 %).

- Gas heating (instead of oil heating) substantially reduces environmental effects irrespective of the blowing agent applied. The 365mfc-blown spray keeps its advantageous environmental profile as compared to the water/CO_2-blown spray. The higher cumulative energy demand as well as the higher contribution to the GWP and POCP of an insulated flat warm roof as compared to a non-insulated roof are compensated by the lower transmission losses of the insulated flat warm roof within the first year of use irrespective of the heating system (figure 5).

<u>Comparison of PU-rigid foam boards for the thermal insulation of a pitched warm roof or a cavity wall</u>

In the standard scenarios (figure 2) the 365mfc-blown boards show a similar GWP (roof) or an app. 6 % lower GWP (wall) and approx. 10 % lower values for all other criteria as compared to the respective n-pentane-blown boards. As compared to the 141b-blown boards the 365mfc-blown boards are found to cause marginally higher (4 – 5 %) environmental effects, avoiding, however, the 141b-born ODP.

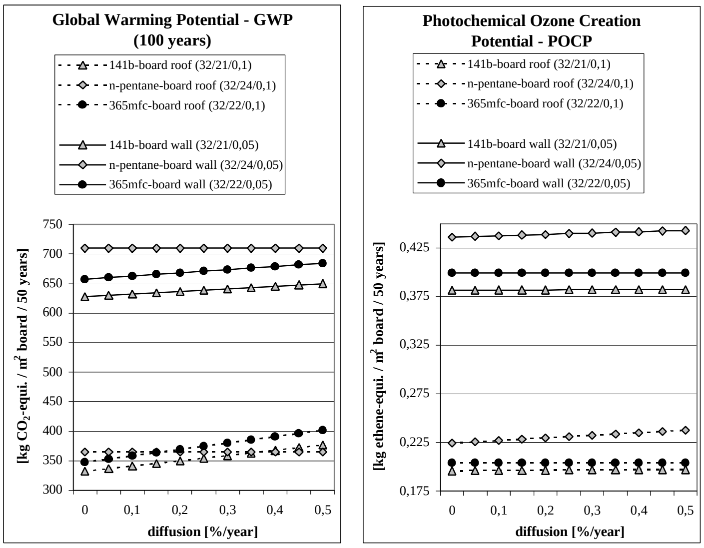

Figure 6: Dependence of the GWP and POCP on variations in the diffusion rates of different PU-rigid foam boards

Shown are standard scenarios with varying diffusions rates of blowing agent for boards with tri-laminate facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)], and the thickness in [m]. For key settings see preceding table.

Sensitivity analyses reveal:

- The environmental advantages of 365mfc-blown boards increase in absolute terms when increasing the service life of the products or under conditions requiring more heating.
- Assuming an increase in blowing agent losses during the service life of the sprays will only affect the parameters GWP, ODP and POCP (i.e. the advantages/competitiveness of 365mfc-blown products with the other parameters remain valid). 365mfc-losses of approx. 0.2 %/a (roof) or 1 %/a (extrapolated; wall) would result in a total GWP that equals the respective value for the n-pentane-

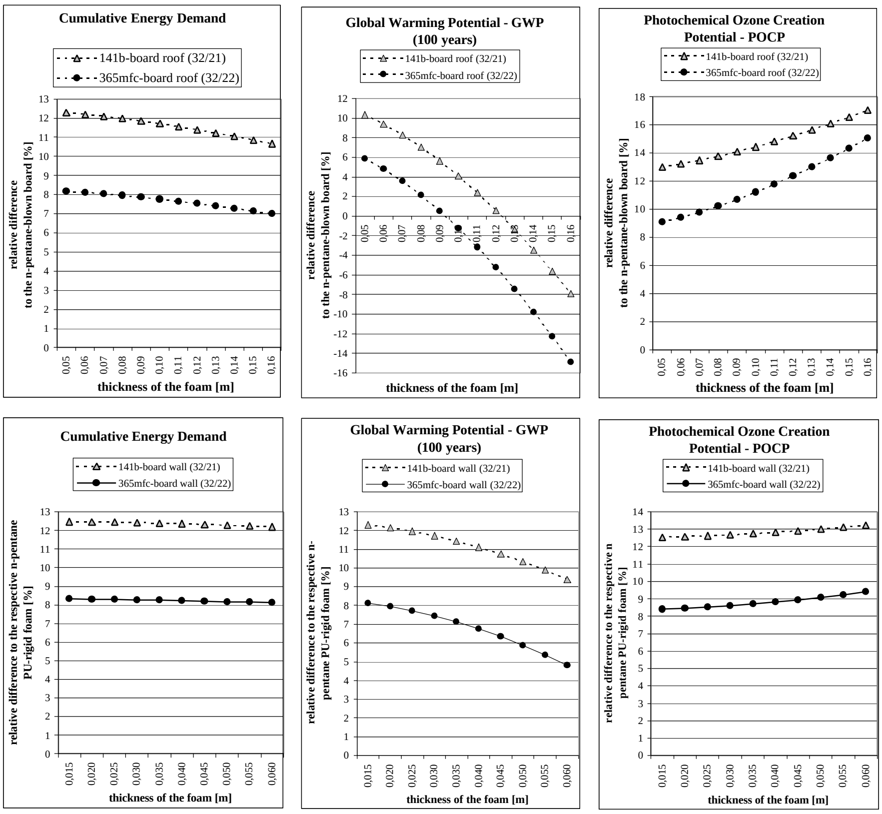

Figure 7: Dependence of the cumulative energy demand, GWP and POCP on variations in the thickness of 365mfc- and 141b-blown PU-rigid foam boards relative to the n-pentane-blown boards
Shown are standard scenarios with varying thicknesses for boards with tri-laminate facings. The upper and the lower set of figures show the results for a pitched warm roof and a cavity wall, respectively. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)]. For key settings see preceding table. Positive values represent environmental advantages while negative values stand for environmental disadvantages.

blown boards (figure 6); such losses are equal to or exceed empirical values.

- Increasing the thickness equally for all boards will not substantially alter the results except for the GWP for which the reduction of heating generated CO_2 is counterbalanced by GWP relevant emissions of blowing agents. Below a thickness of approx. 0.09 m the 365mfc-blown board for the pitched warm roof shows a lower GWP as compared to the n-pentane-blown board. Above this break-even point the

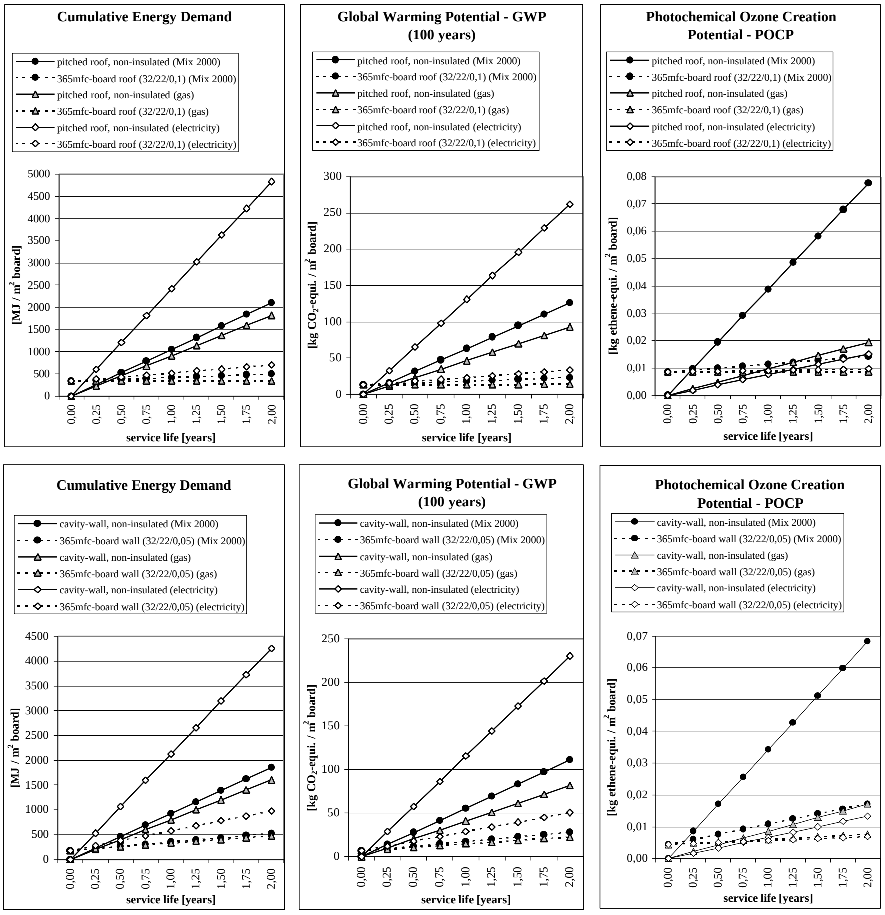

Figure 8: Cumulative energy demand, GWP, and POCP for a non-insulated and an with a 365mfc-blown board insulated pitched warm roof or cavity wall with different heating systems during the first two years of use

Shown are standard scenarios for different heating systems for sprays without facings. The numbers in parentheses refer in sequence to the specific weight in [kg/m^3], to the thermal conductivity in [mW/(m * K)]. The source for the thermal energy is either a representative mix of heating systems in Germany for the year 2000, a gas heating system, or electricity. For key settings see preceding table.

365mfc-blown board shows a higher GWP as compared to the n-pentane-blown board, keeping however its environmental advantages in the other parameters (figure 7).

- To achieve the insulation performance of the 365mfc-blown boards the thicknesses of the n-pentane-blown boards have to be increased by approx. 10 %. For u-values higher than 0.2 W/(m^2 * K) the GWPs for all thermal insulation systems regarded are equally competitive (i.e. differences are below approx. 10 %).
- Changing heating systems may substantially alter environmental effects for both insulation applications irrespective of the blowing agent used. 365mfc-blown boards keep their advantageous/competitive environmental profile as compared to n-pentane boards. The higher cumulative energy demand as well as the higher contribution to the GWP and POCP of an insulated pitched warm roof or a cavity wall as compared to a non-insulated roof or wall are compensated by the lower transmission losses of the insulated roof or wall within the first year of use irrespective of the heating system (figure 8).

Conclusions and recommendations

The results show that the zero-ODP blowing agent 365mfc has the potential to replace 141b to be the standard in environmentally high performing PU-rigid foam insulation products. In a practicable and meaningful range of variations of key parameters 365mfc as a blowing agent offers an opportunity to produce environmentally advantageous or at least competitive PU-rigid foam products for thermal insulation as compared to available environmentally sound alternatives.

Environmental advantages of 365mfc-blown PU-rigid foams are all the more evident when the applicable thickness of the insulation products is limited (e.g. due to spatial or static restrictions) or their service lives are increased.

Apart from aiming at even lower λ-values in the further application development of 365mfc-blown PU-rigid foams, controlling blowing agent losses should be strived for, e.g. by diffusion-resistant facings and by an adequate after-use-management of the products to keep the environmental lead. The full report indicates in detail which properties of 365mfc-blown PU-rigid foam products will result in which overall environmental performance. Thus, the elaborated results can guide further application development, form the basis for product communication, and support considerations regarding marketing activities.