
New HEPA/ULPA filters are an energy-saving option for enhanced safety in hospitals

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Air filters with particularly high collection efficiencies for submicron particles are referred to as High Efficiency Particulate Air filters (HEPA filters) or Ultra-Low Penetration Air filters (ULPA filters). They are mainly used in the micro-electronics and pharmaceutical industries, in medical engineering, and in hospitals. Increasing numbers of HEPA and ULPA filters are also being installed in foodstuffs and cosmetics production facilities for aseptic processes. In all these applications, the objective is either to prevent contamination of a particularly sensitive product with particulate pollutants, or to protect human beings from dangerous micro-organisms and germs by ensuring that the filtered air possesses a defined degree of sterility.

In hospitals, HEPA/ULPA filters are used in the intake air systems of operating theaters and intensive-care units, and in Clean Workbenches for medical technique. HEPA/ULPA filtration is the only way to create what are called Clean Rooms, in which almost all hazardous dusts and micro-organisms are removed from the air involved.

In the manufacture of HEPA and ULPA filters, a new technique has been developed suitable for series production, providing users with filters exhibiting particularly low pressure drops and high reliability in terms of trouble-free operation, collection performance, and freedom from leaks.

■ **Evaluating the collection efficiencies of HEPA and ULPA filters**

The terms “HEPA” and “ULPA” filters have been defined in several European and American standards. The most commonly used of these standards for type-testing HEPA and ULPA filters are British Standard 3928, US Military Standard 282, and DIN 24 184. All these standards apply for air filters with collection efficiencies above those of filters for general ventilation and air-conditioning systems, whose type-testing is described in ASHRAE Standard 52.1-1992 and other standards similar to it. The testing standards for HEPA and ULPA filters are not mutually comparable across the board, which makes it more difficult for users to select their filters. What is more, modern-day methods in media production and manufacturing techniques make it possible to produce high performance HEPA and ULPA filters which are no longer amenable to classification with the various testing methods involved, because the measuring apparatus described in the standards is not accurate enough for assessing these filters effectively.

To remedy this problem, the German Standards Committee for Mechanical Engineering (NAM) has developed the new DIN Standard 24 183. The intention is to introduce DIN 24 183 on a European level as European Standard EN 1822 under the aegis of CEN TC 195 WG2 (CEN, Technical Committee 195, Working Group 2). One of the major advantages provided by DIN 24 183 is its incorporation of ultra-modern measuring techniques and process engineering insights, not only enabling high-performance HEPA and ULPA filters to be metrologically assessed up to collection efficiencies of 99.99995 %,

but also describing a quality assurance methodology.

Figure 1 shows a comparison of European and American standards, plus the new standards DIN 24 183 and EN 1822. As can be seen in Figure 1, DIN 24 183 refers to Filter Classes EU 10 to EU 13 as standard HEPA filters, and Filter Classes from EU 14 and higher as high-performance HEPA filters. EN 1822 designates filters from Classes H 10 to H 14 as High-Efficiency Particulate Air filters (HEPA) and from U 15 to U 17 as Ultra-Low Penetration Air filters (ULPA).

The most important parameter in filter assessment is the collection efficiency in the collection efficiency minimum. The physical basis here is the minimum curve characteristic for assessing the collection efficiency, which describes the separation behavior of fiber-type filters and thus of HEPA and ULPA filters (see Fig. 2).

The minimum lies in the transitional area between stochastic movement (diffusion) due to Brownian molecular movement and the inertial effect as determinant collection mechanisms. The position of the collection efficiency minimum for a HEPA or ULPA filter, both in terms of the percentage collection efficiency and of the particle size with the highest penetration, depends on the velocity of the air stream flowing through the filter medium. For a given filter, any change in the air volume flow passing through will shift the position of the collection efficiency minimum. The particle size with the highest penetration at a given filter medium passage velocity is referred to as the “Most Penetrating Particle size” (MPPS).

Fine dust filters	EN 779 F 9							
HEPA / ULPA filters		H 10	EU 10	Q	EU 10	95%		
		H 11	EU 11	R	EU 11			
		H 12	EU 12	S	EU 12		99,97%	
		H 13	EU 13		EU 13		99,99%	
		H 14	EU 14		EU 14		99,999%	
		U 15	EU 15					
		U 16	EU 16					
		U 17	EU 17					
			EN 1822	DIN 24 183	DIN 24 184		BS 3928 and BSI-Dok. 90 / 73 834	Mil-STD 282

Fig. 1 Comparison of international filter classes in broad conformity with DIN 24 183 T1-E, Appendix A

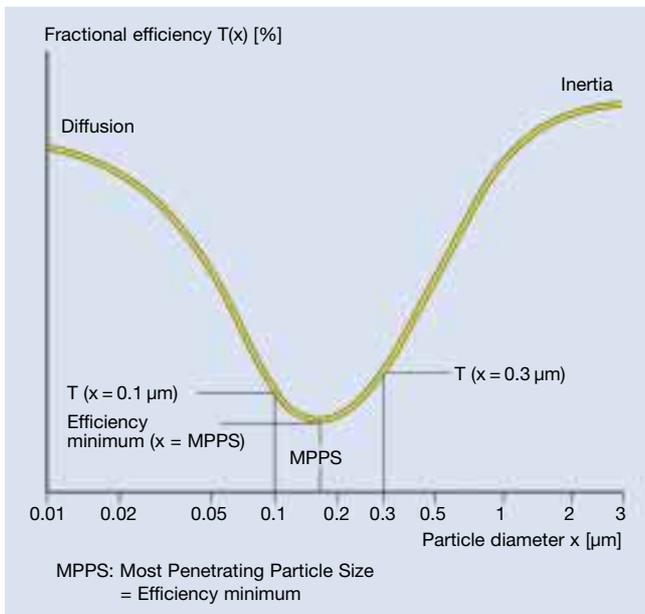


Fig. 2 Minimum curve of a HEPA filter medium

HEPA/ULPA filters in hospitals

In hospitals, Hepa filters are used in several areas. One of their major applications is at operating theaters, where of course the air has to be kept practically free of dust and germs. Depending on the requirements involved for air sterility, different concepts must be employed for air supply: given medium requirements for room air quality (fewer than 150 - 200 germs/ m^3), it will generally be sufficient to provide what is called turbulent mixed ventilation, where the fresh air is mostly fed into the room through ceiling outlets featuring integrated HEPA filters (usually Class H 13 according to EN 1822), and mixed with the room air (see Fig. 3).

With this air supply configuration, factors affecting the dust and germ content include the number of air changes per time unit, and design features for air flow guidance.

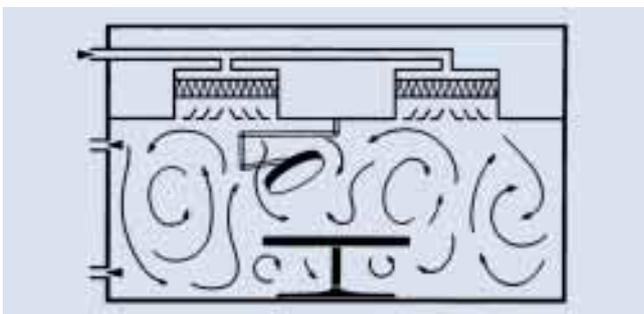


Fig. 3 Operation theater with turbulent mixed ventilation

In order to achieve concentrations of fewer than 10 germs/ m^3 (frequently demanded for the area directly above the operating table), the recommended air supply configuration is what is called low-turbulence displacement flow, where the operating table is continuously enveloped in a veil of ultra-pure air, shielding it off from its surroundings.

The usual air velocity is 0.25 m/s to 0.45 m/s, and the temperature of the air flow is 2° to 3°C below that of the room air.

Two different systems are employed in hospitals to achieve a low-turbulence displacement flow. In one of these, the intake air is passed through HEPA filters (Class H 13) installed in the air duct shortly before reaching the ceiling of the operating theater, and then dispersed over the operating table with the aid of a distribution system, which mostly comprises a double layer of stretched, finemeshed synthetic woven, ensuring the desired homogeneous air distribution effect by means of a certain pressure drop and its very uniform mesh structure (see Fig. 4a).

In the second system, the ceiling area above the operating table is fitted with HEPA/ULPA filters (Class H 13 or H 14). The intake air is thus filtered directly as it flows into the operating theater, and is homogeneously distributed with the aid of the filters themselves (see Fig. 4b).

In another important hospital application for HEPA filters, the Clean Workbench, the system of low-turbulence displacement flow likewise plays a central role.

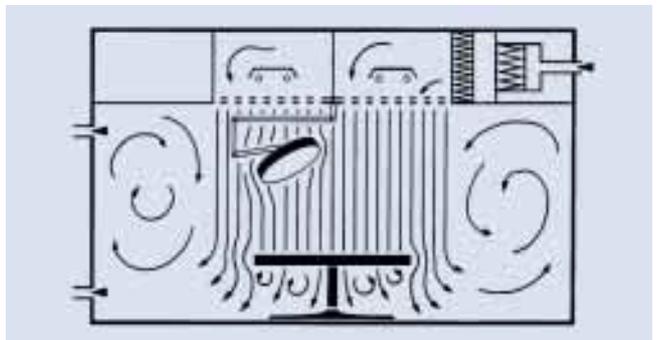


Fig. 4a Operation theater with low-turbulence displacement flow over operation table, HEPA filters in the air duct

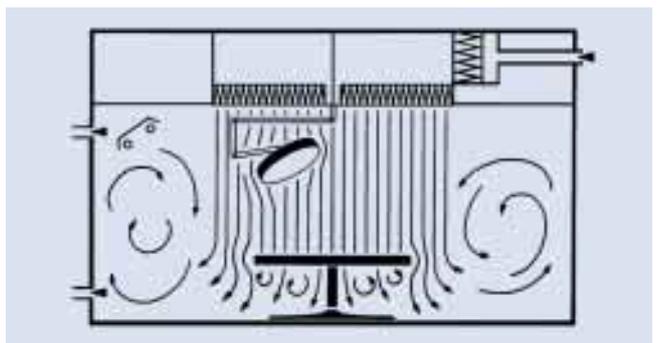


Fig. 4b Operation theater with low-turbulence displacement flow over operation table, HEPA filters in the ceiling

In Clean Workbenches, a worktable is bathed in purified air, in order, for example, to prevent a sterile medicine being contaminated by airborne germs. If a hazardous substance (e.g. cytostatic agents) is being handled on the worktable of the Clean Workbench, the exhaust air from this workbench must also be purified with HEPA filters. For Clean Workbench applications, the HEPA filters employed are usually Class H 13 or H 14. As with the ceiling filters in operating theaters, it is important to use a HEPA filter with precise, uniform pleat geometry, since the degree of laminarity in the downstream air is closely dependent on the pleat geometry involved.

■ Design variants for HEPA/ULPA filters

If high percentages of particles smaller in size than $1\ \mu\text{m}$ are to be collected in a fiber filter, then wet-laid micro-glassfiber papers must be used as the filtering medium. Only these filtering media permit cost-efficient production of filter elements with the requisite collection efficiency performance.

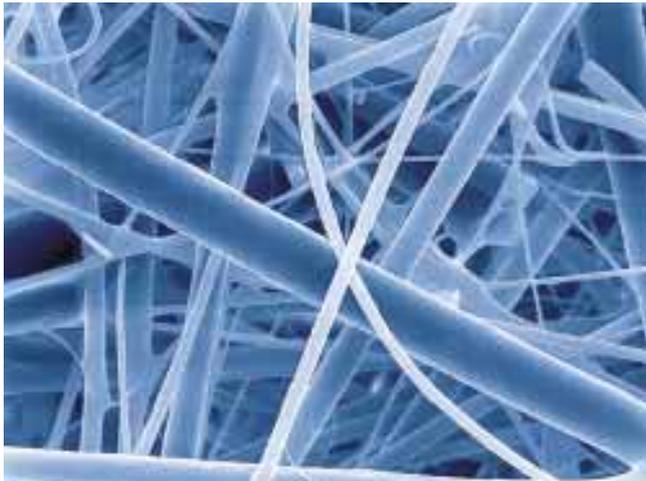


Fig. 5 Thermally embossed micro-glassfiber paper 5 μm

Figure 5 shows a scanning electron microscope (SEM) picture of one of the glassfiber papers typically used in HEPA/ULPA filters. The fiber diameter, an important factor in filter performance, is in the range of $0.1\ \mu\text{m}$ to $0.3\ \mu\text{m}$. The larger-diameter fibers also visible in the SEM picture are intended to increase the filtering medium's mechanical stability, and constitute only a small percentage of the overall fiber blend. Micro-glassfiber papers exhibit a relatively high packing density with low thickness, resulting in comparatively high pressure drops over the material concerned.

The relatively high pressure drop for this filtering medium means that as much filtering medium as possible has to be accommodated inside a limited installation space in order to enable sufficiently large quantities of air to be passed through a HEPA filter. In this context, the spacer design is crucial to the operationally determinant parameters, like collection efficiency, pressure drop, dust holding capacity and useful lifetime, mechanical stability or grade of turbulence of the downstream clean air.

The oldest spacer design is represented by what are called separator filters (see Fig. 6).

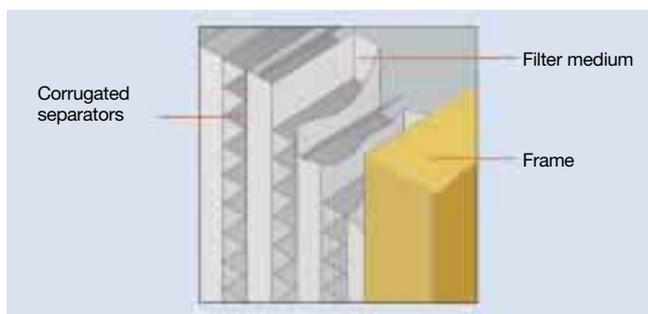


Fig. 6 Separator technique

In most cases, a corrugated aluminium foil is inserted between the layers of the filtering medium, in order to prevent the

medium layers touching each other and thus deactivating parts of the filtering area. Pleat depth in separator filters is frequently approx. 270 mm to 280 mm. However, the separator design means that approx. 20 % of the total filtering area is lost at the bent edges of the separators, since no air can pass through between two touching bent edges.

In actual operation, these sharp-edged aluminium separators frequently have an adverse effect on the sensitive micro-glassfiber paper, which can easily be punctured or damaged. These holes in the filtering paper can be caused not only during the production process, but also and especially during transport and installation of the filter elements concerned. After the HEPA filters have reached the end of their useful lifetime, proper disposal often necessitates separating the aluminium from the glassfiber paper, a timeconsuming and costly procedure.

The use of separator filters has proved particularly problematical for semiconductor manufacturing operations in the micro-electronics industry, which currently poses the most stringent requirements for minimized particle content in the purified air. The aluminium separators began to oxidize over the course of time, and released particles into the purified air flow. And under vibration conditions, chafing metal separators caused hairline cracks to form.

These problems triggered the development of what is called the minipleat thread design, where a thread made of glassfiber or cotton and coated with adhesive is used as the spacer (see Fig. 7).

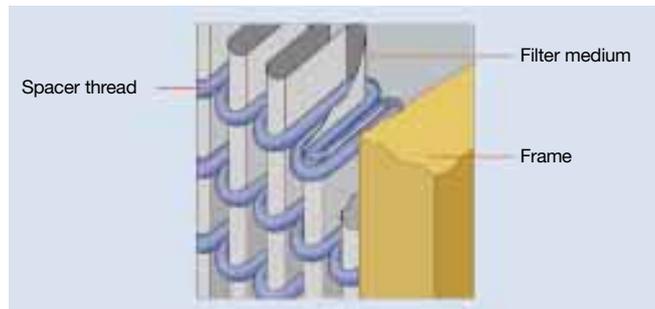


Fig. 7 Minipleat thread technique

A refinement of this minipleat design has meanwhile emerged, with a simple hot melt thread acting as the spacer.

The threads are applied to both sides of the glassfiber paper approx. 25 mm from each other, and after pleating will touch each other in the assembled pleat pack. Advantages of this minipleat design include the elimination of sharp-edged metal separators, and (compared to conventional separator designs) the opportunity to pleat more closely, thus accommodating more filtering area in a defined installation space. The disadvantage involved is the relative instability of the pleat pack, entailed by the low inherent rigidity of the filtering medium and the assembly technique selected. This means that with the minipleat design pleat packs can be produced only to a maximum pleat depth of 180 mm, which of course limits filtering medium area with reference to the face area.

This limitation on achievable pleat depth led to development of the minipleat V-filters, where pleat packs of small pleat depths are arranged in a V-shaped configuration, so as to accommodate sufficient filtering area in a customary installation depth of 300 mm (see Fig. 8).

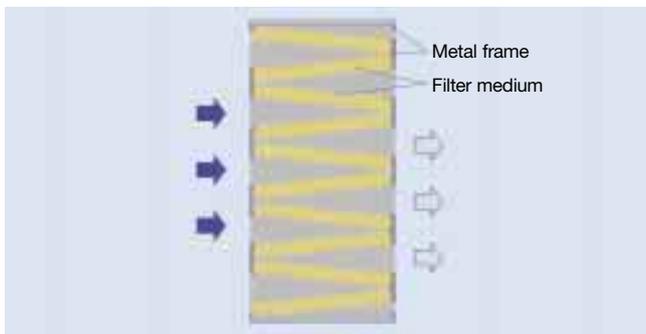


Fig. 8 Minipleat V-filter

A minipleat V-filter's design means it can be used only in applications where the turbulence of the downstream air is of secondary importance, since the deflections of the air flow as it passes through the filter, plus the partial blockage of face and outlet areas at the filter element, result in severe air turbulence. In systems with low-turbulence displacement flow, minipleat packs must be positioned at right angles to the flow, which in turn entails the use of Minipleat filters with a maximum pleat depth of 180 mm and concomitant lower limits for pressure drops.

For reasons of sealing efficacy between the up to ten filtering medium packs and the filter frame, minipleat V-filters usually find it essential to use metal as the frame material, i.e. more easily disposable materials like wood can hardly be used. The sealing problems between the outer filter frame, the vertical supports and the individual pleat packs necessitate using large quantities of sealing compound, rendering the filter elements heavy and clumsy.

The thermal embossing technique constitutes a new development in the field of HEPA/ULPA filter manufacturing. It enables pleat packs of up to 280 mm in depth to be created without having to use any foreign materials as spacers.

A complementary pair of embossing rolls imparts conical dimples and the later pleat tips onto heated micro-glassfiber paper (see Fig. 9).

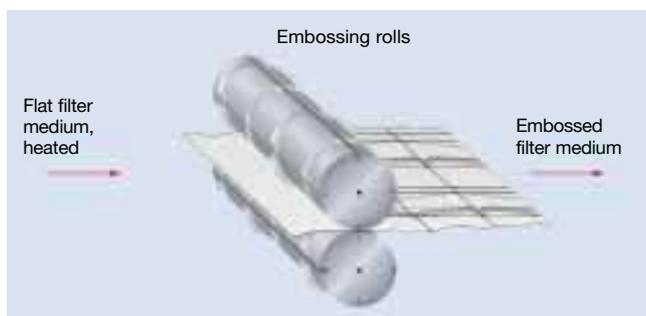


Fig. 9 Thermal embossing process

The glassfiber paper is finished with a special thermoplastic bonding agent, which becomes soft and fluid at a defined temperature range, thus permitting the embossing function; after it cools down it sets hard, rendering the embossed configuration permanent. The shape of the protrusions on the embossing rolls enables aerodynamically favorable, V-shaped pleat geometries to be achieved. As Figure 9 shows, the shaping elements alternately protrude into or out of the paper level. After subsequent pleating, the dimples thus formed will touch each other, spacing out the filtering medium in both upstream and downstream directions (see Fig. 10).

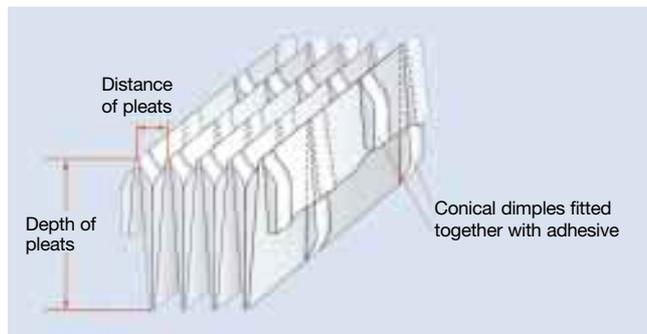


Fig. 10 Thermal embossing technique: no additional spacing materials

Before pleating, a fine film of spray adhesive is applied to these dimples, effectively fixing the pleat pack in its final shape. At the end of the production process, a thread of adhesive is affixed at right angles to the pleat tips, thus providing added stability to the pleat pack in the machine direction. Figure 11 shows in diagrammatic form a filter element manufactured with the thermal embossing technique.

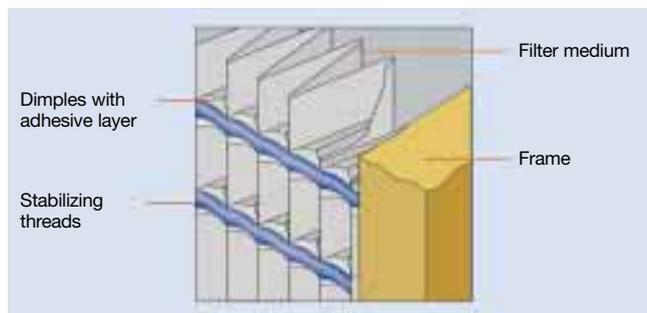


Fig. 11 Thermal embossing technique

The thermal embossing process enables pleat packs to be produced with pleat depths of up to 280 mm and widths of up to 1220 mm all in one piece. The V-shaped pleat geometry entailed by this process forms the basis for extremely homogeneous flow conditions throughout the filter element, since the air is offered a maximized cross-sectional area as it enters the pleat and subsequently exits from the downstream pleat (Fig. 12).

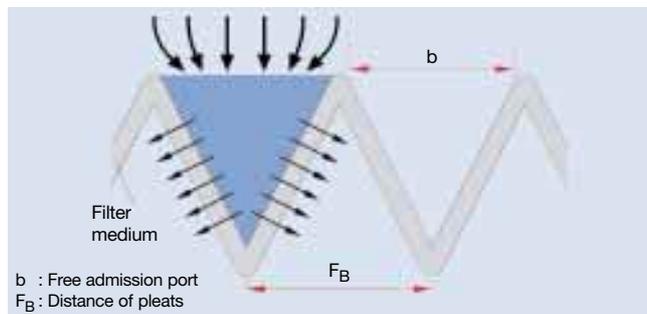


Fig. 12 V-shape pleat geometry

Inside a pleat, the flow velocity remains practically constant, since air mass flow and cross-sectional area simultaneously become smaller on the upstream side and larger on the downstream side.

Using the thermal embossing process HEPA and ULPA filters can be built either with high air volume flows for a given pressure drop or with particularly low pressure drops at a constant face velocity.

The first of these options is important when a ventilation system is to be dimensioned for a given air volume flow. Compared to the conventional separator filters on the market, the newly developed HEPA/ULPA filters, with filter elements of the same size, can cope with air volume flows approx. 40 to 50% higher for the same pressure drop, thus enabling more compact systems to be built.

In comparison to the minipleat V-filters described above, the design provides options for significantly simpler and more functional assembly. A filter element manufactured with the thermal embossing process consists of only one filter medium pack and the four frame components. This considerably simplifies the sealing between the filter medium and the frame, even when wooden frames are used. The quantity of sealing compound required is minimized, thus reducing the filter's weight and facilitating its disposal.

The thermal embossing technique combines the characteristics listed below:

- ▶ low-turbulence air passage and downstream flow due to aerodynamically optimized V-shape of the pleats and equidistant, precise pleat geometry
- ▶ low pressure drops or high volume flows due to pleat depths of up to 280 mm
- ▶ very good utilization of the filtering area installed, thanks to high ratio between active and gross filtering area
- ▶ gentle folding of the filter medium while still warm, thus avoiding micro-cracks on the pleat tips
- ▶ no foreign materials as spacers
- ▶ manufacture of 1220 mm wide and 1830 mm long pleat packs in one piece.

This offers numerous advantages for operators of clean rooms and air handling units with HEPA/ULPA filters:

- ▶ reduced energy costs in operation thanks to low pressure drops
- ▶ high degree of laminarity in the downstream air
- ▶ significantly reduced risk of damage to the filter medium during transport and installation
- ▶ avoidance of corrosion problems when using metal-free filters or filters with corrosion-proof frames (e.g. aluminium)
- ▶ low disposal costs for metal-free filters.

■ Summary

The newly developed thermal embossing technique unites the advantageous characteristics of separator and minipleat thread designs. Without using any foreign materials as spacers, pleats can be produced up to a depth of 280 mm, thus enabling disposal-friendly filters with low pressure drops to be manufactured. The V-shaped pleat geometries created by this process ensure homogeneous air flow throughout the entire filter medium, and low-turbulence downstream airflow. The exceptional stability of the filtering medium pack permits filters to be produced in widths of up to 1220 mm and lengths of up to 1830 mm in a single piece, without any connecting ribs. This makes a significant contribution to enhanced safety in hospitals, providing protection from dangerous germs and also reducing energy costs.