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bining light pipe and stack ventilation – some development aspects

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.CT

: aims to develop a light-vent unit combining light pipe technology and passive stack ventilation ng the light pipe as an exhaust stack. This system can be further integrated with a novel design of to heat or cool the building.

: contains several aspects related to the use of light pipes and stack ventilation. A study of the information on the main building types and their morphology in several European countries has determine the most suitable regions for this technology. It seems, that the most potential ypes are educational, office and retail buildings.

o enhance the natural stack ventilation and to prevent reverse flow, a wind terminal is installed o of the light-vent pipe. Several types of terminals have been investigated. The best performing ıriant of the "h-pot" and the "umbrella" type have been investigated further. The umbrella type htly higher air flows but both types have a positive effect on the functioning of the ventilation.

development of a light collector is included in the work. Results of modelling have shown, that ncept to be economically feasible, a well performing collector is essential. It seems, that static s are not able to guide enough light into the pipe and that a one-axis or two-axis tracking system

EYWORDS

es; Stack ventilation; Natural ventilation; Renewable energies.

NTRODUCTION

ng is one way to utilise renewable energies in buildings. It provides light that supplements or electric lighting. Amongst the different daylighting technologies, light pipes offer considerable es because daylight can be transmitted to virtually any space throughout the building. Natural on is being applied to an increasing number of new and retrofitted buildings across Europe. The advantage of natural ventilation lies mainly in the fact that it consumes no electricity and so produces no harmful emissions, has no running cost, no noise of operation, involves no moving parts, requires little maintenance and is therefore reliable. Until now daylighting and natural ventilation techniques have been developed independently and form separate systems. By integrating the two functions to form one system, several advantages are achieved.

The basic idea is to guide daylight in to the building and air out of the building using an integrated structure. This is called a light-vent pipe, Fig. 1. In the middle of the structure is the light pipe, lined with a highly reflecting material. At the top of the pipe is a light collector, catching light and guiding it into the pipe. At the lower end of the unit is a light diffuser spreading the light into the room. The light pipe is surrounded by an annular space, which acts as a stack for the exhaust air. At the upper end of the stack is a wind terminal, enhancing the flow and preventing reverse flow. The whole structure can be round or rectangular. A rectangular shape fits better to a corner or close to the wall. If there are several floors to be served, two strategies are available. Either each floor has its own light-vent pipe, or only one pipe penetrating all floors is used and the light and air have their own openings at each floor.

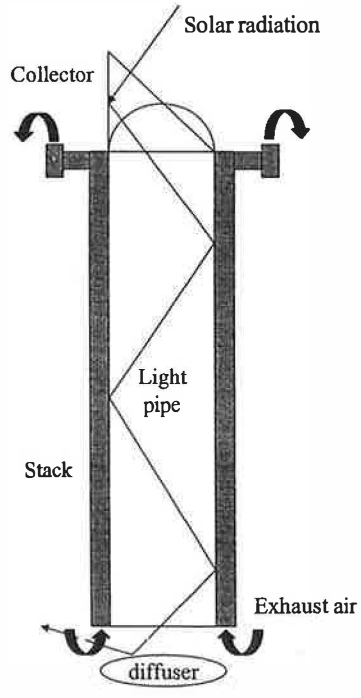

Fig.1 Principle of the light-vent pipe.

This struc re can further be integrated with a thermosyphon based cooling system. The evaporator inside the room is connected through vertical pipes to the condenser on the roof. The vertical pipes, which contain the circulating working fluid and vapour, can be a part of the vertical light-vent pipe structure.

ARCHITECTURAL DESIGN ISSUES AND APPLICATION POTENTIAL

Buildings, which can be adequately daylit and ventilated from the perimeter are unlikely to benefit from a concept like the light-vent pipe. The limit is usually taken at 6 metres from the perimeter for both single coded daylighting and ventilation. Most potential is in existing buildings where the plan depth is greater than 12m. The introduction of vertical shafts may represent a significant planning constraint, but are likely to be more acceptable if aligned with partitions. In addition, isolated spaces (e.g. meeting rooms) detached from the perimeter would benefit even in shallow plan buildings.

It is important that the role of the light/vent pipe is clearly integrated within the overall environmental strategy for the building. Daylighting availability must be linked to effective artificial lighting control to make use of the potential savings. Ventilation strategy must be linked to thermal design of building, acoustic and fire zoning.

The legislation governing fire protection in buildings in the four countries (UK, Finland, Portugal and Switzerland) has been reviewed to determine the general implications for the integration of light/vent pipes. As anticipated the requirements are fairly similar in the different countries. Generally, the casing of ventilation ducts passing between floors of a building must be incombustible and have a fire rating equivalent to the compartment floor or wall through which it passes. In some circumstances, fire dampers located between floors can be provided as an alternative to non-combustible shaft construction.

Statistical information on the characteristics of the National building stocks in the UK and Finland have been obtained, and a detailed morphological study of the non-domestic building stock (NDBS) has been reviewed for the UK. This has enabled preliminary conclusions to be drawn on where there is greatest potential in refurbishment of retrofitting of light-vent pipes to existing buildings. In the UK, there appears to be considerable potential in applying the technology to existing educational, office and retail buildings. These building types represent just over 33 % of the NBDS by area. In Finland, offices, educational and commercial buildings represent approx. 40 % of all NDBS, and since morphology is fairly similar throughout Europe, there would appear to be significant potential in these building types.

HYDRAULIC DEVELOPMENTS

The main objectives of the hydraulic development part were to determine the optimum dimensions of the annular air channel and to produce a working design for a suitable wind terminal at the top of the stack. Different terminals were designed for use with the light-vent pipe. Fig. 2 shows the different configurations considered. Two of them correspond to an open pipe exit (open channel). One terminal was named "umbrella type" and two variants of the "H-pot type".

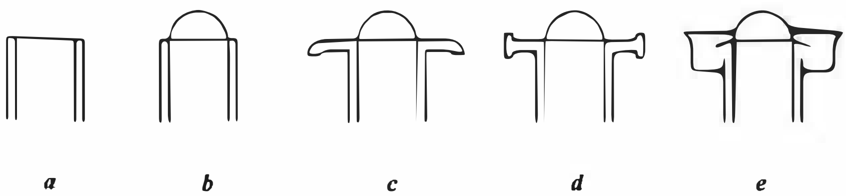

Fig. 2 Different ventilation terminals: ***a*** – open channel, flat top; ***b*** – open channel, hemispherical dome; ***c*** – umbrella type; ***d*** – H-pot type 1; ***e*** – H-pot type 2.

CFD simulations were undertaken to compare the performance of different pipe terminals: open channel, umbrella type and H-pot type. The finite element (FE) method was applied to solve the governing set of partial differential equations using the ANSYS 5.5.1 commercial program package for Windows NT operating system. 3D modelling was used. Results of computations for horizontal wind direction are summarised in Table 1.

Table 1 The effect of horizontal wind speed on flow rates for the different terminals.

Terminal	a	a	a	b	b	b	c	d	e
Wind speed m/s	0	2	4	0	2	4	2	2	2
Flow rate l/s	9.7	57.5	169	9.4	15.6	30.8	3.0	19.2	13.9

For a horizontal wind direction there is a strong wind effect on ventilation rate, even with the high indoor-outdoor temperature difference (20 K) considered. The plain duct (a) has the highest flow rates. This construction is, however, not very attractive from the light collection point of view. Lower flow rates for the hemispherical dome construction are due to a high-pressure zone near the exit of the channel on the dome windward side, which adds a downstream flow resistance.

For a 45° upward wind direction the computations reveal a negative (reverse) flow for terminals c and e. The highest positive (exhaust) flow is for terminal b. For a 45° downward wind direction terminals a and b indicate a reverse flow. The H-pot 1 terminal (d) is the only one leading to positive flow rates for all wind angles. Furthermore, the resulting flow rate is very stable for all angles. Therefore, this terminal seems to be the best choice for use with light pipes. Further empirical investigations of types c and d show, that in terms of flow rates the umbrella type (c) gives slightly higher flow rates than the H-pot, but both types have a positive effect on the functioning of ventilation.

OPTICAL DEVELOPMENTS

In order to deliver sufficient daylight into the building, a light pipe has to have a large diameter to length ratio or/and be equipped with an effective light collecting device. The task of the collector is to catch light and guide it into the pipe in a close to vertical direction, to prevent reflection losses in the pipe. The collector can be static, rotating (around one axis) or tracking. It can also be concentrating or not concentrating. Some devices, like the laser cut panel, just change the direction of the rays closer to vertical.

In the optical development part, several static collectors were investigated using a laboratory facility. The facility consisted of a measurement box, a light pipe, the collector to be tested and a light source. Illuminance sensors were installed inside the box and the light pipe was attached to the box. The collector was put on the top of the pipe. The illuminance levels in the box achieved by the light source were measured. To achieve different altitude angles, the light source was moved along the perimeter of a circle. To achieve different azimuth angles, the collector was turned around the light pipe axis.

Several static type collectors were tested: a clear dome, several constructions of flat and pyramid- shaped laser-cut panels, reflecting skew-cut cylinders (see Fig. 1), flat reflectors and reflectors having a curved surface. The plain pipe without any collecting device was used as a reference. Fig. 3 shows an example of laboratory measurement results.

Conclusion from the laboratory measurements is that static collectors can give rise to remarkable increase of the amount of collected light, but only during a short period during the day. The amount of light guided into the light pipe greatly depends on the sun azimuth and altitude angles. Collectors directed towards south can greatly increase the illuminance in the middle of the day, but have no effect or can even have an adverse effect during the mornings and the evenings.

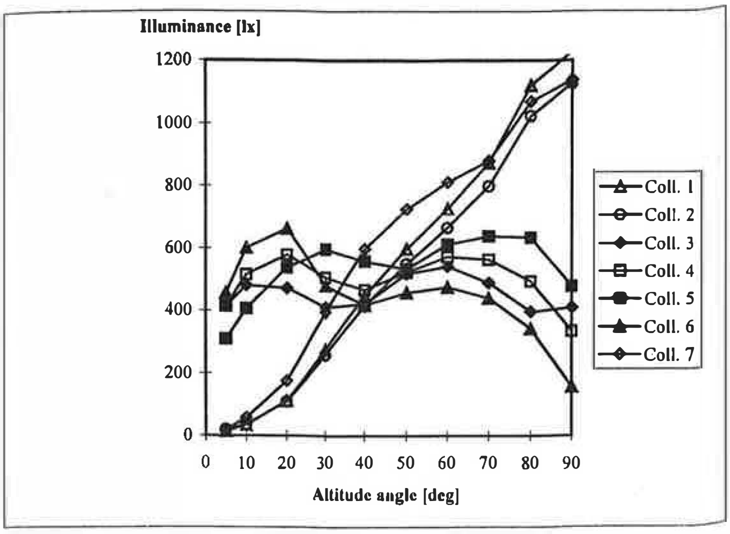

Fig. 3 Measured illuminance levels in the box for different collectors as a function of the altitude angle. Coll. 1 is the reference (no collector).

The laboratory measurements concerned only beam radiation without the diffuse component. To obtain information for the collector performance under natural conditions, some field tests were carried out. The results were in line with the laboratory measurements. Further, it seems that some of the collectors, like the laser-cut panel, perform worse in natural lighting conditions because of their blocking effect. Also a water-filled Fresnel lens was tested, but it was absorbing too much light to be effective.

The optical developments part contained also an experimental investigation to evaluate the optical characteristics of a dichroic material in order to assess its potential for light pipe applications. The dichroic material used in the tests reflects visible light while transmits infra-red radiation. Consequently the infrared part would be absorbed by the pipe wall and only the visible light would enter the room. Tests were carried out in laboratory conditions. The irradiance of infra-red and illuminance of visible light were measured both before and after a dichroic disk. These data were then used to calculate transmittance values.

Table 2 Transmittance of dichroic glass for both visible light and infra-red radiation.

Incidence angle [deg]	0	10	20	30	40	50	60	70	80	90
Infrared transmittance	75.20	75.00	74.70	76.40	76.10	74.80	66.20	23.20	1.30	0.00
Visible light transmittance	0.50	0.60	0.70	1.00	1.90	4.40	4.00	5.00	1.60	0.00

The results showed that application of dichroic material in light-vent pipe would enhance the flow rates, greatly reduce solar heat transmitted to occupied spaces in summer, while maintaining relatively high daylight transmittance.

ECONOMICAL ASPECTS

The economical aspects of a light-vent pipe were treated by estimating the simple payback period (SPP), the energy payback period and the price for the saved energy (PSE). The savings through the use of natural light were calculated using a simple light pipe model based on the measurements carried out during the previous phases. The computations were made for three different climatic regions. Finland represents the cold climate, Switzerland the moderate, and Portugal the southern climate.

Fig. 4 shows an example of the cumulative value of a light-vent pipe investment. When the pipe is installed, its financial value is negative and corresponds to the paid costs, 800 euros. After the installation, the pipe begins to save energy and the payback procedure starts. After one year a certain amount has been saved. The number of years needed to repay the investment is the payback period. At this time the value of the pipe is zero. If the life period is longer than the payback period, the value of the pipe is positive and the win period can start. The SPP for the southern region, around six years, is reasonable. The SPP for the moderate and cold regions is not feasible from an investment point of view.

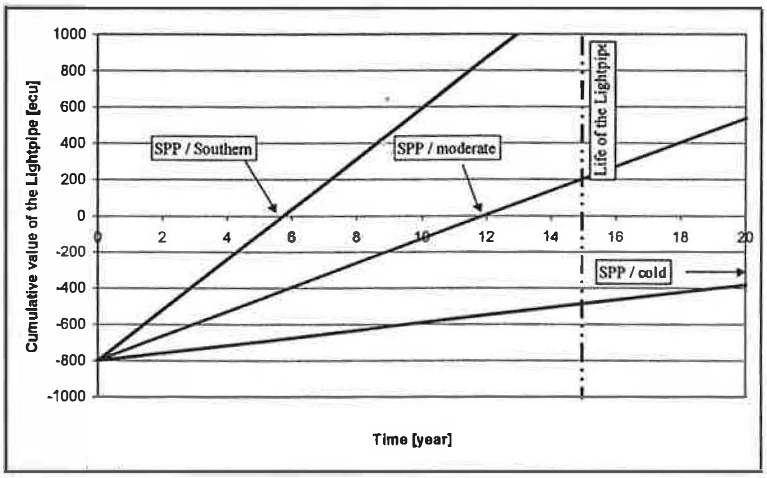

Fig. 4 An example of the estimated cumulative value of a light-vent pipe investment.

FUTURE WORK

A preliminary estimate is, that a light-vent pipe could be a feasible concept in a right type of building located in a right climatic region. Any final conclusions can not be drawn, as the work is not finalised. Further work comprises some work on the light collector, laboratory scale measurements in natural conditions and testing of a thermosyphon cooling option. The final stage is the construction, installation and monitoring of a pilot-scale light-vent pipe. After the monitoring results have been analysed, final conclusions will be drawn.