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Abstract

As a result of global warming, reliability and sustainability of the operation of modern light-emitting diodes (LED) is compromised. We describe the principles how to catch and use the generated waste heat coming from lighting with LED sources thanks to a novel device called “MESLED MODULE” able to change its operation mode during the year. Thanks to this feature, the optimal form of waste heat is reached. With waste heat it creates a thermal barrier from top to reduce thermal losses or provide preheat. Described is the possibility of standardizing the cooling system in the interiors with the same device. The same working fluid can be used to cool down the space and LEDs in one multifunctional device. This "all in one" solution prevents fire and increases the lighting time in the event of a fire alarm. The article highlights the most important application in greenhouses that can increase food security. An efficient transformation of electricity into light and heat can create interesting interoperability between the energy and agriculture sector and use this novelty in the state of the art with added value.

Keywords	LED light source; waste heat utilization; cooling system; preheating; thermal barrier; demand and response
Taxonomy	Solar Assisted Heat Pump, Combined Cooling Heating Systems, Direct Lightning, Waste Heat Recovery System, Integration of Renewable Power Source, Hybrid Renewable Energy Technology

Corresponding Author	Zoltán Kováč
Order of Authors	Zoltán Kováč

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Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
No data was used for the research described in the article

- Utilization of waste heat from artificial light sources can provide overall comfort
- Active fluid cooling of LEDs increases its lifetime, energy efficiency of building and fire safety
- Optimization of waste heat provides an active thermal barrier from top in winter
- The multifunctional energy system standardizes the cooling system in buildings
- Photosynthesis can be continuously used to support intermittent RES applications

Novel multifunctional energy system called "MESLED" powered by LED light and heat source

Zoltán Kováč

MESLED ENERGY Ltd.
Slovak University of Technology in Bratislava, Slovak Republic
Faculty of Electrical Engineering and Information Technology
Institute of Power and Applied Electrical Engineering

Abstract
As a result of global warming, reliability and sustainability of the operation of modern light-emitting diodes (LED) is compromised. We describe the principles how to catch and use the generated waste heat coming from lighting with LED sources thanks to a novel device called “MESLED MODULE” able to change its operation mode during the year. Thanks to this feature, the optimal form of waste heat is reached. With waste heat it creates a thermal barrier from top to reduce thermal losses or provide preheat. Described is the possibility of standardizing the cooling system in the interiors with the same device. The same working fluid can be used to cool down the space and LEDs in one multifunctional device. This "all in one" solution prevents fire and increases the lighting time in the event of a fire alarm. The article highlights the most important application in greenhouses that can increase food security. An efficient transformation of electricity into light and heat can create interesting interoperability between the energy and agriculture sector and use this novelty in the state of the art with added value.

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1 Introduction

In the 21st century, each building should lower the negative impact on the environment and use renewable energy sources and effective technologies. Each building must be equipped with a set of technologies to provide all the necessary conditions for human existence. The required range of technical equipment depends on geographic location, climatic conditions and building characteristics. Generally, it is necessary to provide light intensity, all-year heat conditions (heating and cooling) and a certain level of air exchange. The application of energy efficient technology in new buildings is already achieved thanks to better economic results (return of investment) and energy certificate requirements, which reflects the available effectivity of technologies on the market. The same situation also arises in reconstruction of technology in existing buildings. The main reason why this reconstruction usually starts with the lighting system is the visible effect, increasing the safety, and interesting return of investment with today’s modern LED light sources. Compared with standard light sources the achievable saving is around 60%. This is the reason why the market with LED luminaires grew up very quickly, especially the range of available quality. Reliable thermal management is the most important during the operation of high-power LED luminaires. It means the producers apply passive cooling for LED chips with enough quantity of materials with the best thermal conductive properties (aluminum), already for low power LED luminaires. This passive cooling feature reflects the level of LED luminaire quality and the most important parameters in its datasheet, thus the light efficiency and the lifetime. The lighting designers must respect the maximum ambient temperature, especially in old buildings without thermal insulation. They must adapt the correct passive ability of LED luminaire to cool down the LEDs which is becoming more and more challenging due to global warming. Since the offer with LED luminaire quality is extensive, the range of needed investment has an impact as different returns of the investments. Unfortunately, this value is still the key during the decision for investors [1].

2 IMPORTANCE OF ACTIVE COOLING FOR LED LIGHT SOURCES IN THE FUTURE

Every light source is the source of heat at the same time. The part of electricity consumption which transforms to waste heat is a very effective source for its re-usage. The conductive form of generated waste heat from modern LED light sources represents a huge opportunity for its placement into the working medium (fluid) and ensures its efficient use. It allows using the waste heat and increases sustainability and reliability over time and in the case of a fire alarm since the circulating fluid has a higher cooling capacity than the passive cooler used for standard LED luminaires. Modern high-power LEDs can convert nearly 30% of input of energy to visible light. The rest 70% of electricity consumption is converted to unutilized waste heat which has a big potential for its further utilization and commercialization. The global warming effect increases the maximum ambient temperature in interiors during the summer period. With this is also related the possibility to exceed the maximum allowed ambient operation temperature for standard LED luminaires. The smart electric driver inside can measure and log those temperatures, which could have a negative impact on the future complaint process with the producer (seller). Unfortunately, without a cooling system in those places, the maximum ambient temperature is not controlled by the user. Of course, the waste heat generation from the lighting system has a negative impact on human comfort in the critical summer period. Without a right technical solution, it has no positive impact in winter because thermal gravity keeps this heat under the ceiling.

From the future point of view, we must develop a technical solution able to adapt the operation mode by actual season and optimally use the waste heat from LED light sources during the whole year. For any light efficiency in the future, it will always be a fact that LEDs (semiconductor component) is a source of the heat at the same time and its active fluid flow cooling increases its reliability, lifetime and our fire safety. Heat generated by LED sources has an impact on the thermal expansion of the used materials in luminaire (glass, plastic, metal, etc.) and together with high ambient temperature it reduces also the lifetime of LED diodes. The glass optic cover of a luminaire has a rubber seal that suffers from degradation by thermal load. Its destruction may cause a failure of water resistance of the luminaire. The removal of waste heat generated by LED sources can avoid such a problem. Just with waste heat utilization we are currently able to assume an acceptable payback period for modernization of standard LED luminaires in the future.

3 DESIGN OF MULTIFUNCTIONAL DEVICE

Standard LED luminaires must provide all necessary conditions for the integrated light source but cannot provide the possibility of using its generated waste heat. To achieve this, the new multifunctional device must be equipped with a heat exchange surface between the LEDs and the working fluid and a heat exchange surface between the thermal energy and the interior. Own air source (fan) is preferred to provide heat/cold into the interior from heat exchangers. With these features it is possible to create a multifunction device and achieve total indoor comfort with just one device. Only a combined own source of light, heat and air allows the annual efficient and optimal utilization of waste heat from LEDs as shown in Fig. 1.

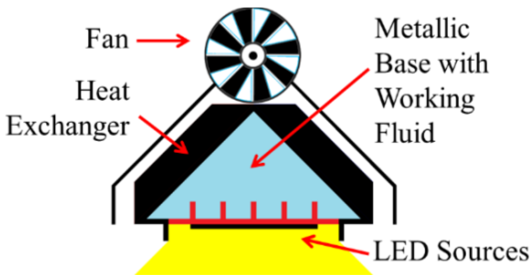


Fig. 1. Joining all technical sources of indoor conditions in one device.

The triangular shape is the best way how to ensure the highest heat exchange area and use the air flow from the same fan. Heat exchange ability is reliable not only for heating but mainly for the indoor cooling process when thermal gravity makes this process more effective. In the case of condensate formation, the triangular shape can capture it and ensure drainage. Fig. 2 shows the detail construction of the multifunctional device called “MESLED MODULE”. As mentioned, the triangular shape of metallic base (1) was designed to ensure reliable condensate drainage (8) during the cooling period, connected to the pipes (9). The enlarged heat conductive surface with elements on the structure (2) provides the best heat transfer from the LED sources in used COB form (6) to the circulating working fluid. Similar elements on the outside (3) allow hermetic implementation (5) of LED sources with fixed connection (4) of a transparent light diffuser (7). Designed is a double heat exchanger (10) to maximize the heat change surface. A device is designed with its own air blower (15) to ensure independent regulation of all possible conditions in the local area. This means two side radial ventilators (14) with electromotor (12) in the middle, connected with a rotary axis (13). The airflow must be effectively focused on the heat exchangers with a right shape of the air diffuser (16). Its thermal insulating property is an advantage.

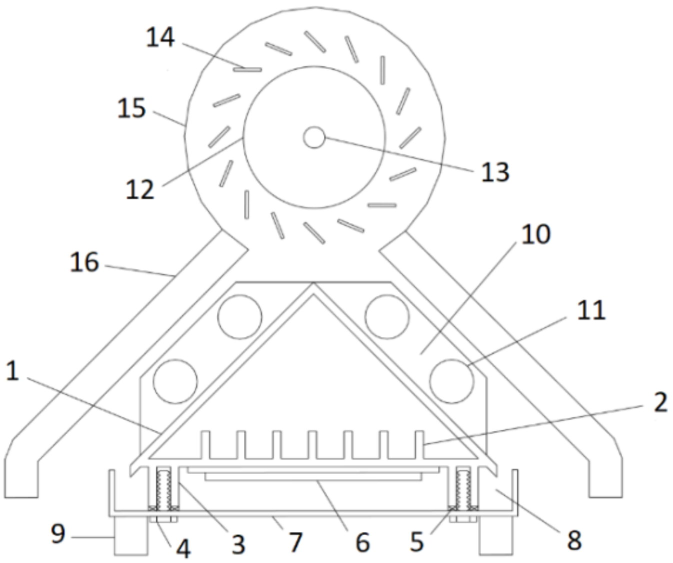


Fig. 2. Cross-sectional view on first design of multifunctional device [2].

The detailed construction design must respect all auxiliary needed components as shown in Fig. 3. It is important to terminate the metal base with two end elements (17). For eliminating the load under the weight of upper elements, it is necessary to use a structural strength element (18). To keep a sufficiently hermetic level for the LED sources the device uses an IP grommet for cable (19). The fixed attachment (20) of the electromotor must be professionally solved with maximum noise elimination (21). The suction of air must be only through the filter surface (22) to keep the clean level inside the device. Elimination of the load of pipe joining under the total weight and vibration requires to use strong fixating elements (23).

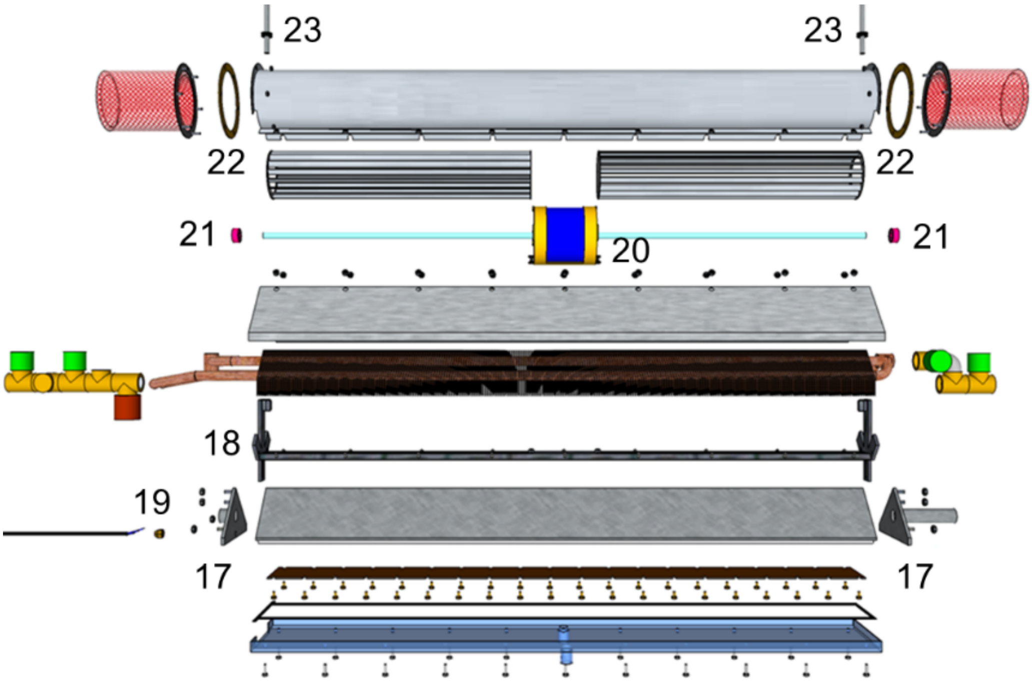


Fig. 3. Detailed construction of device.

Since the design of standard LED luminaires is variable, the used LED light source inside varies, too. The presented multifunction device can unify the used light source. Fig. 4 shows the use of a LEDs of strip form (24). The most important elements to achieve the multifunction features are a pair of electric valves connected in series with integrated pump (25) joined with an input demountable element (26) and a pair of electric valves (27) connected in parallel joined with the output demountable element (28). The air blower must be dust protected by side filters (29). The length of the device is optional in the range of the air blower length, thus the total light and thermal power of the device is adjustable.

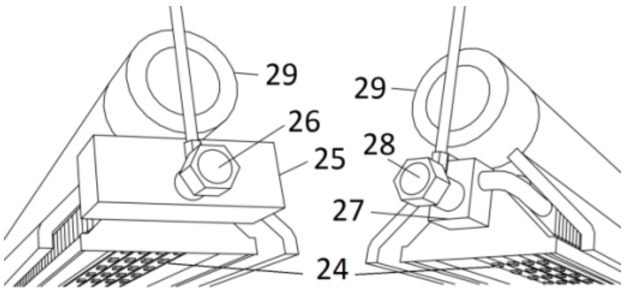


Fig. 4. Front and back sides of designed device [2].

4 Three Operating Modes for Efficient Yearly Thermal Comfort

From the point of view of thermal comfort, we can generally divide the annual operating time T_{YEAR} into three parts: time without changing the ambient temperature $T_{(OK)}$, time with heating demand $T_{(+)}$ and time when we need to decrease the ambient temperature $T_{(-)}$.

$$T_{YEAR} = T_{(OK)} + T_{(+)} + T_{(-)}$$

Lighting, heating and hot water technology are the basic devices in each building. Climate change is increasingly causing the same view of the cooling system. Since the investment in the cooling system is used seasonally, the return of this investment does not exist. Sometimes it would only be enough to take away the waste heat from lighting out of the space to achieve the right thermal comfort. But since this is not achieved, the energy consumption of the cooling system is higher (if applied). It must cover the unwanted heat generation during lighting [3]. In each season, a certain level of light intensity is required, thus the waste heat production from lighting is almost continuous. The heat demand changes during the year. Based on this, a multifunction device was designed with three different operation modes OM1, OM2 and OM3 achieved thanks to the four electric valves changing the free way of the working fluid circulation inside the device. [1,2]

In the first operation mode OM1 the working fluid directly flows through the metallic triangular base with fixed LED sources and takes their generated waste heat during the time $T_{(OK)}$. The obtained heat gain can be used to produce (preheat) hot water or for production heat in industry. As this time represents a significant part of the year, direct flow eliminates the performance of the circulating pump.

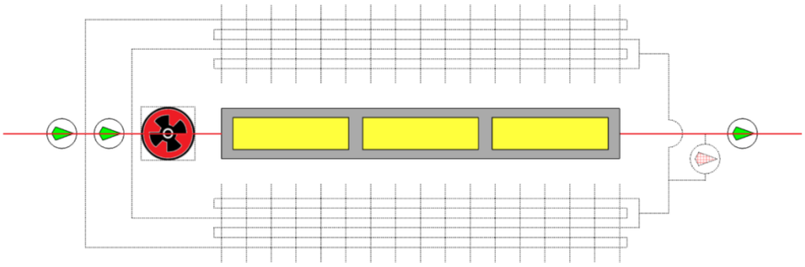


Fig. 5. Operation mode OM1.

The second operation mode OM2 represents the exchange of incoming thermal energy (heat/cold). The working fluid first flows into the integrated heat exchangers. After thermal energy exchanging it flows through the metal base to take the waste heat from LEDs if they are active. During the winter in the same multifunctional device, heat exchange with space and preheating is realized. During the summer in the same multifunctional device, cooling and waste heat removal is realized.

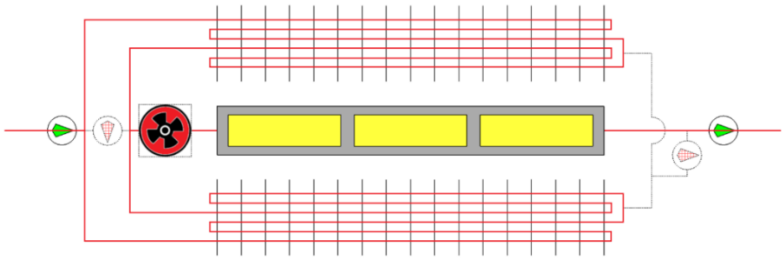


Fig. 6. Operation mode OM2.

The third operation mode OM3 works with a closed fluid circuit when the integrated small pump is active. The waste heat from LEDs is directly transported into the heat exchangers and distributed into the space. Blowed warm air above overcomes thermal gravity.

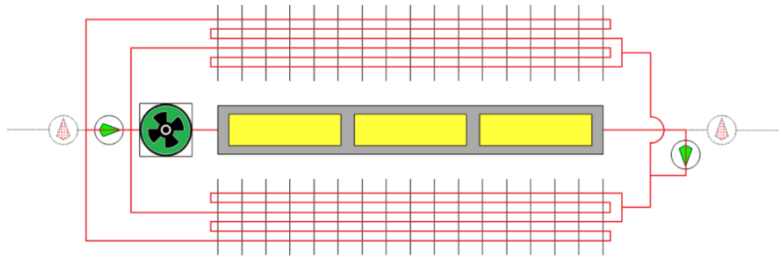


Fig. 7. Operation mode OM3.

The multifunction device uses the waste heat from LEDs directly inside, where it was generated (operating mode OM3 in time $T_{OM3(+)}$) or store it in the working fluid (operating mode OM2 in times $T_{OM2(+)}$ and $T_{OM2(-)}$). Or, it works without thermal demand in time $T_{OM1(OK)}$ and directly takes the waste heat from integrated LEDs with flow through the metallic base (operating mode OM1). Then the equation for total annual operating time of the device/system is:

$$T_{YEAR} = T_{OM1(OK)} + T_{OM2(-)} + T_{OM2(+)} + T_{OM3(+)}$$

This means that the total time range with the heating demand $T_{(+)}$ includes two operating modes. The first one with a lower thermal power when the required ambient temperature can only be achieved with the generated waste heat from LEDs (e.g. transition period) and the other mode, when the incoming heating heat is distributed by devices and providing efficient preheating with LEDs. The sample of annual operation mode ratio is show in Fig. 8.

$$T_{(+)} = T_{OM2(+)} + T_{OM3(+)}$$

Fig. 8. Year-round time of operating modes.

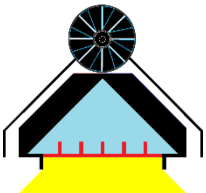
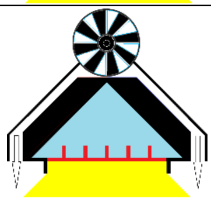
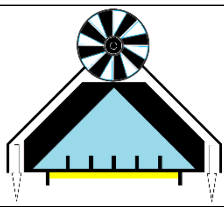
5 Eight Different Functions for Basic Human Needs

Thanks to the three operating modes, an integrated heat exchanger and its own light and air source, the multifunctional device can provide eight functions that meet basic needs of people (organic life) throughout the year.

In the year without the need to change the ambient temperature $T_{(OK)}$ people certainly need a sufficient level of light intensity, air exchange or both. This means it is necessary to provide three functions listed in Table 1. Then the equation for this kind of total time is:

$$T_{(OK)} = T_{F1} + T_{F2} + T_{F3}$$

Table 1. Functions without need to change the ambient temperature.

Function		Time	Fluid Flow	LED	Air Source	Operating Mode
F1 Light & Heat gain		T_{F1}	External	ON	OFF	OM1
F2 Light & Heat gain & Air flow		T_{F2}			ON	
F3 Air flow		T_{F3}	OFF	OFF		-

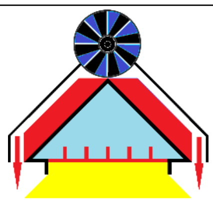
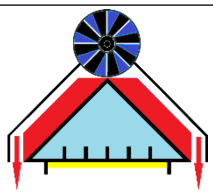
In many countries the most energy demanding period is the time with heat demand. The ratio between working modes OM2 and OM3 depends on climate, geographical location and building characteristics (e.g. height, thermal insulation, etc.).

It is likely that in some situations there is an effective increase in light power to avoid the activation of the main heat source and heat losses on the heat transfer. In this case the negative impact of glare must be solved by the device [5].

Is not excluded that in higher installation a more effective heating methodology exists. For this reason, it is advantageous to work in OM3 to distribute waste heat from LED sources by blowing warm air, which can reduce thermal losses due to thermal gravity. The total annual time of heating $T_{(+)}$ therefore consists of the three functions listed in Table 2 and determines:

$$T_{(+)} = T_{F4} + T_{F5} + T_{F6}$$

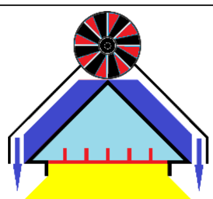
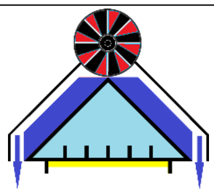
Table 2. Functions with heating operation.

Function			Time	Fluid Flow	LED	Air Source	Operating Mode
F4	Light & Heat gain & Air flow & Heating		T_{F4}	External	ON	ON	OM2
F5	Air flow & Heating		T_{F5}		OFF		
F6	Light & Air flow & Heating only with waste heat from LEDs		T_{F6}	Own	ON		OM3

In Table 3, two cooling functions are specified, in which only the light activation is different. In case of an active light source, its waste heat is taken with the same working fluid, what can reduce the power of cooling if the waste heat in the working fluid is efficiently broken down or use. Equation for this total annual time of cooling $T_{(-)}$ is:

$$T_{(-)} = T_{F7} + T_{F8}$$

Table 3. Functions with cooling operation.

Function			Time	Fluid Flow	LED	Air Source	Operating Mode
F7	Light & Waste heat removal & Air flow & Cooling		T_{F7}	External	ON	ON	OM2
F8	Air flow & Cooling		T_{F8}		OFF		

The sum of all times of functions represents the actual annual working time in the interior because the estimated annual total operation time always reflects only the time of human activity. It is important to count the times of preparatory functions, means functions without light source activation before human coming (F3, F5, F8), show in Fig. 9.

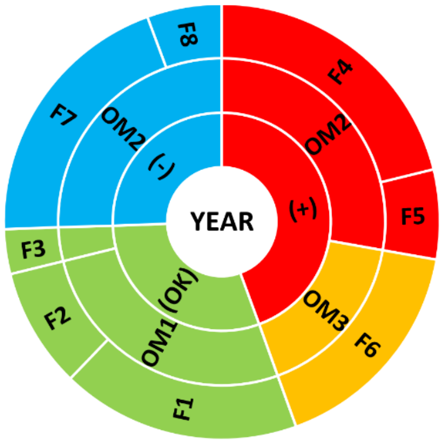


Fig. 9. Total annual working functions [4].

6 RANGE OF USABLE WASTE HEAT FROM LED LIGHTING

Since the free path for the working fluid in the device depends on the operating modes, the total thermal loss is variable [1]. We estimate 25% of thermal loses as a coefficient $k_{LOSS}=0.75$. The measured obtained waste heat power from LED strips with water circulation was 72% of the electric power [5]. For this theoretical calculation we assume 60% of waste heat power from electric power to consider light efficiency of todays and near future LED light sources, since the development of LED light sources is still in progress ($k_{HEAT}=0.60$). Then the general equation of usable heat Q_i is:

$$Q_i = k_{HEAT}\, k_{LOSS}\, E_i = 0.60\ \ 0.75\ \ E_i$$

$$Q_i = 0.45\, E_i \quad i = 1,2,3$$

where E_1 is the power consumption of LED sources during operation, when we expect utilizing the generated waste lighting heat for hot water preparation in times T_{OK}. The multifunction solution assumes dimming by daylight harvesting for light. If the average total power of LEDs is P_{LED}, then the yearly usable waste lighting heat for hot water preparation is:

$$Q_1 = 0.45\, P_{LED}\,(T_{F1} + T_{F2})$$

The power consumption of LED sources E_2 during operation mode *OM2* belongs to the heating period (F4), when the waste lighting heat is used as preheating for the main heat source. If we expect the same average total power of LED sources P_{LED}, the quantity of this part of annual waste lighting heat is:

$$Q_2 = 0.45\, P_{LED} T_{F4}$$

In the case with a heat pump cooperation the energy saving can be higher since the obtained heat from lighting can be used for preheating to increase the coefficient of performance (COP) during the heating period with the heat pump.

The special operating mode OM3 can decrease the needed heat produced by the main heat source and reduce thermal loses (thermal barrier from top). In this case the solution effectively using the full range of LEDs power consumption without heat losing on its transport. As mentioned, an increase of the average total power of LEDs P_{+LED} (light intensity) exists for electricity consumption E_3. The equation of this part of waste lighting heat is:

$$Q_3 = 0.45\, P_{+\,LED}\, T_{F6}$$

This multifunction energy solution considers the LEDs as a source of the light and heat with total annual heat production Q_{LED_YEAR}:

$$Q_{LED\_YEAR} = Q_1 + Q_2 + Q_3$$

7 OTHER ADVANTAGES

Fig. 10 shows how it is possible to increase the function range of the device thanks to the work with fluid – water. It means the implementation of sprinklers (1) for firefighting with the same software regulation (2), which must evaluate a suitable temperature for safe firefighting. In this case the system can increase the safety level in interior, where the fire fighting system is not required by legislation because we assume non-active firefight function in the heating process due to high temperature of working fluid. With enough fluid filtration can implement an own cleaning element for light optic (3) in those interiors where it is possible to be ready for this cleaning process. Lighting efficiency is sustainable not only for LED light sources (active fluid cooling), but also for devices in conjunction with working fluid. If this multifunctionality is applied in a greenhouse, the same solution may be used to increase humidity during summer periods.

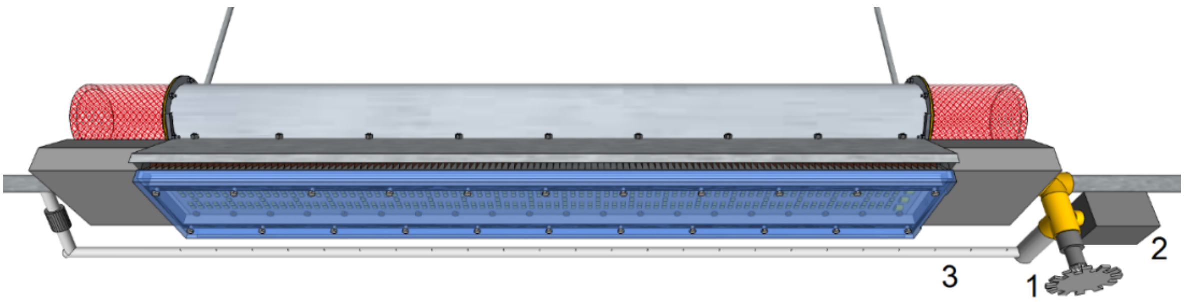


Fig. 10. Additional elements to increase the scope of use.

The integrated center-mounted electric motor with two radial fans provides two independent air suctions. Unconnected one or both provide a certain level of heat recovery during heating process as shown in Fig.

11. The application of a radial ventilator with one longitudinal air suction provides a higher level of this heat recovery and increases the filter area but does not allow the combined work with the HVAC duct and air present. Thanks to the working air passing through the device, it is possible to integrate an suitable UV light source for disinfection of the working air.

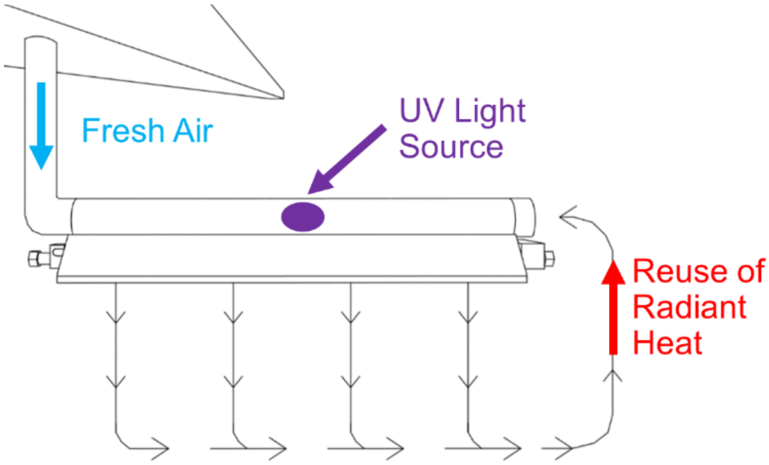


Fig. 11. Other possible functions of the device

The multifunctional device focuses on an efficient use of the entire range of LEDs power consumption. Not only with the use of waste heat, but also with part of lighting consumption due to the biodynamic change in temperature colour according to the current time. In this case, the emitted light temperature corresponds to natural light, which increases mental well-being and reduces stress and non-production in industry.

8 WORKING INFRASTRUCTURE FOR MULTIFUNCTIONAL SYSTEM

The system needs multiple types of infrastructure for all-year operation as shown in Fig. 12. To keep the safety during jointed work with electricity and fluid it is necessary to apply a safe DC low voltage power supply (A). Interactive regulation of all conditions needs data connection (B). Thermal insulation of the pipe infrastructure (C) is the key to effective operation during the whole thermal processes, excluding the operation mode OM3, when the active working fluid is only inside the device. The hygienic solving of the formed condensate during the cooling process is made by a drainage pipe (D). Working with fresh air from the exterior is preferred embodiment which needs to apply a HVAC duct infrastructure (E).

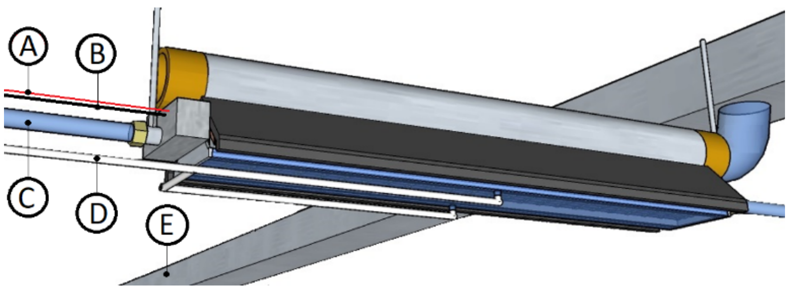


Fig. 12. Specification of needed infrastructure

9 METHODOLOGY OF ECONOMIC ANALYSIS

If the energy efficiency of the presented system should be higher than of standard solution, we need to compare its yearly energy balance with the most effective existing solutions. For this reason, the analysis uses the solution with heat pump as the main source of heat, cold and hot water according with Table 4, to compare standard (old) and presented (new) solution.

Since the study respects the design stage of the presented system, we expect higher needed total investments for the new technical “MESLED” solution, even though it has a multifunctional feature and can replace more todays individual system (I_{OLD}□I_{NEW}).

Without doubt we can expect some energy saving thanks to utilization of generated waste lighting heat. Then the main economic parameter is the time of payback *T* of increased total investment *ΔI*, thanks to the total yearly financial saving S_{YEAR}.

$$T = \frac{\Delta I}{S_{YEAR}} = \frac{I_{NEW} - I_{OLD}}{S_{YEAR}}$$

where I_{NEW} and I_{OLD} are the total needed investments, thus the sums of individual investments for specified technologies, according to Table 4. If the € is the total average price for one megawatt of electricity, then the equation for yearly saving is:

$$S_{YEAR} = \left[€ \left(E_{OLD} - E_{NEW}\right)\right] + S_{S\&M} - N$$

The multifunction property of the only technical device needed in interior can probably save the yearly cost for service and maintenance $S_{S\&M}$. As written above, the system using higher installed power of LED sources can represent the negative saving value *N* as increased cost for reserved capacity.

This methodology of analysis can objectively review the comparable scope of using those two solutions, including all kinds of achievable savings. It also includes the saving on cheaper heat devices as is the heat pump or the boiler with a lower heating power during heat preparation thanks to utilization of waste lighting heat. It does not neglect the savings on heat distribution during operation mode OM3, when the heating sources are inside the interior (heat loses on transport).

Table 4. Needed investment decomposition of standard solutions and of presented system with yearly energy balances

COMPARED CHARACTERISTIC OF TECHNICAL SYSTEMS		THE PURPOSE OF TECHNICAL SYSTEM							
		Lightning	Air exchange	Heat recovery	Cold	Heat	Cold	Heat	Hot water
					Distribution		Production		
OLD	DEVICE	LED Luminaires	Destratification		Fan coils units		Heat pump A		
	INFRASTRUCTURE	Cabling 1	Cabling 2		Drainage pipes	Pipes with insulation			
	SOFTWARE	Software 1	Software 2		Software 3		Software 4		
	INVESTMENT	*I_{OLD1}*	*I_{OLD2}*		*I_{OLD3}*		*I_{OLD4}*		
		The total investment of standard way $\boldsymbol{I_{OLD}}$							
	ELECTRICITY CONSUMPTION	*E_{OLD1}*	*E_{OLD2}*		*E_{OLD3}*	*E_{OLD4}*	*E_{OLD5}*	*E_{OLD6}*	*E_{OLD7}*
		The total sum of yearly electricity consumptions $\boldsymbol{E_{OLD}}$							
NEW	DEVICE	Multifunction devices					Heat pump B		
	INFRASTRUCTURE	Cabling			Drainage pipes	Pipes with insulation			
	SOFTWARE	One common regulation software							
	INVESTMENT	*I_{NEW1}*					*I_{NEW2}*		
		The total investment with presented system $\boldsymbol{I_{NEW}}$							
	ELECTRICITY CONSUMPTION	*E_{NEW1}*	*E_{NEW2}*	-	*E_{NEW3}*	*E_{NEW4}*	*E_{NEW5}*	*E_{NEW6}*	*E_{NEW7}*
		The total sum of yearly electricity consumptions $\boldsymbol{E_{NEW}}$							

The greatest possible risk for a multifunctional system is a potential threat to human safety. The total system operating weight (including working fluid) is higher. It can affect the static properties of existing buildings. Year-round operation and multifunctional use confirm the need for enough testing under real conditions. High risk in people's premises is the leakage of working fluid, which can cause property destruction. For this reason, we can only concentrate on applying a new multifunctional system in greenhouses, where potential risks are eliminated. Of course, in this case, the appearance of the new device/solution is irrelevant.

10 High Innovation in Greenhouses

An artificial source of light and heat (LEDs) is needed if the natural light and heat source (sun) is inactive. This synergy effect among artificial and natural light sources is perceived from the viewpoint of day and night, also of summer and winter season. The most significant application of this phenomenon is in area where sunlight is a key - greenhouse. Since the multifunctional device contains all the technical sources to provide basic organic needs (light, heat/cold and air), it supports crop cultivation throughout the year and almost anywhere.

As a result of climate change, the ideal temperature in greenhouses is uncontrollable with the standard solution (fans and sun screens). We can't rule out that the crops are or will be threatened due to increasing temperature in summer. If so, the food security is or will be threatened, too. We can say that each greenhouse is built where groundwater is available. The temperature of this water is around 12 °C in the summer. Since the multifunction device must provide the required lighting, the total heat-transfer area of the solution is higher than for today's cooling solution. This confirms the direct usability of free geothermal cold to achieve an ideal temperature for crops. The level of crop production can increase and can be independent of global warming.

High energy costs and low thermal insulation of glass and foil limits winter operation of many greenhouses. Their production potential is not being used as much as possible. The impact is high costs and low quality of available fruit and vegetables. Since there is a significant number of luminaires in each greenhouse, we can expect a homogeneous active thermal barrier from top in operation modes OM3 and OM2. The energy intensity of winter operation decreases if the heat is kept inside. In both cases, waste lighting heat is used to create an active barrier (in OM3 - directly, in OM2 - preheat). In part of the year without temperature changes, waste lighting heat can be stored or used to heat irrigation water for crops (operating mode OM1). Integrated fan in multifunctional device can be active anywhere. It provides oxygen exchange for dense planting. In this case, the needed carbon dioxide for photosynthesis can be distributed by joined HVAC ducts. The basic seasonal operations described in Fig. 13.

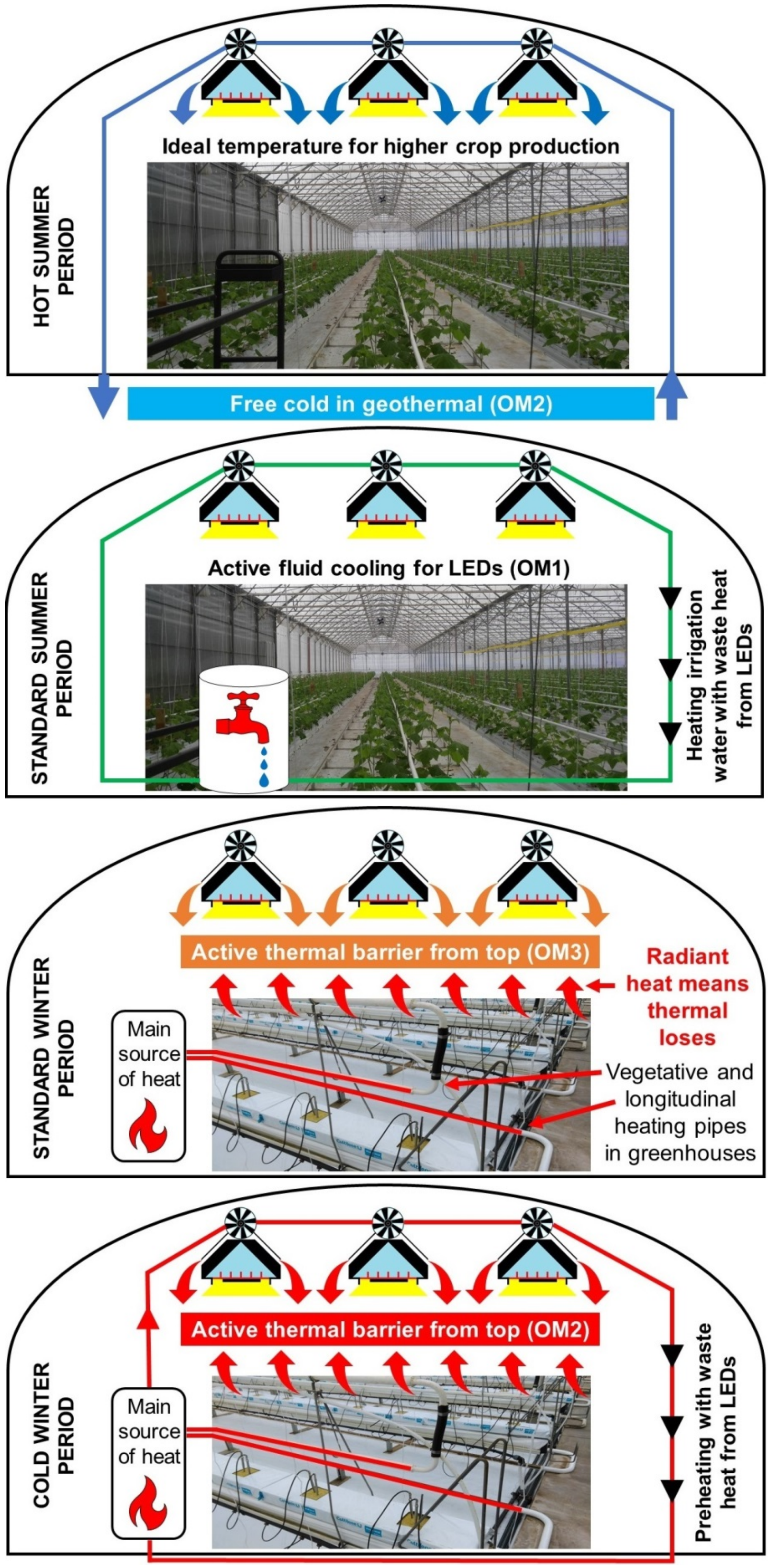


Fig. 13. Seasonal operation of multifunctional system in greenhouse.

11 Effective and Sustainable Demand and Response Element in Power Grid

Pollution is an insidious by-product of civilization that threatens the quality and integrity of our air, our soil, our water and infrastructure. The planet has a remarkable ability to cleanse itself. One example is photosynthesis, in which the oxygen-carbon dioxide cycle is sustained by regeneration of oxygen from the carbon dioxide of respiration and oxidation [6]. Global energy policy has caused an increasing implementation of renewable energy sources (RES) to reduce emissions [7,8]. The creation of the power grid in the past did not expect dynamic changes caused by photovoltaic panels and wind turbines. However, it is rarely possible to economically advantageous accumulate electricity in the power grid. The main goal in power engineering is to solve this increasing problem – intermittent feature of RES. It is inevitable to ensure reliable and safety electricity distribution with the most possible RES production and resilience. The most possible way is to build accumulation, optimization, create Smart grids and elements with Demand and Response features [9].

Prefer electricity consumption (Demand and Response) before accumulation means using this energy effectively. Combination of light and heat production by LED sources of "MESLED" solution represents an efficient and safe way to create a Demand and Response element in greenhouses for plant growing. The full range (excluding system thermal losses) of electricity production causing overload in the power grid can be effectively used as shown in Fig. 14. In Table 5 are listed all positive assumptions that make sense of use greenhouses to support grid stability.

Table 5. Positive assumptions of the greenhouse as Demand and Response

Positive		
Feature	***Usage***	***Impact***
Presence of crops	Irrelevant regulation of light intensity	Year-round response
Placed outside of residential areas		Irrelevant light smog
Photosynthesis	CO_2 reduction	Higher production
Light & heat production	Utilization of waste energy	Energy efficiency
Active fluid cooling		Sustainability
Waste heat optimization	Thermal barrier	Winter operation
Total area of greenhouses	Power & diversification	RES applicability

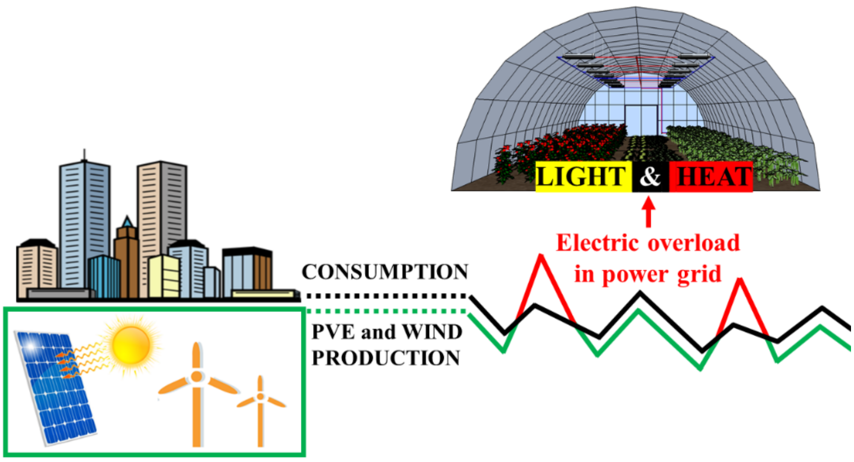


Fig. 14. Demand & response element in greenhouses for plants growing [4].

Regulating the energy balance on the consumption side using the presented multifunctional system, increases the photosynthetic process during plant growing and uses waste heat production according to the current season or needs. This means that the heat is distributed directly into the greenhouse (OM3), or it is taken away by the working fluid for accumulation and use at night (OM1) or as preheat to produce enough heat (OM2). Only with presented solution is possible to optimally use synergic effect of the light to ensure winter operation of greenhouse. Creating a thermal barrier will provide a year-round availability of the Demand and Response feature. To achieve this goal, development must solve the main negative aspects listed in Table 6.

Table 6. Negative aspects of the greenhouse as Demand and Response

Negative		
Feature	***Threat***	***Solution***
Total weight	Statics of the greenhouse	Components dimension
Purity of suction filters	Weak heat/cold exchange	Maintenance / air ducts connection
Uniformity of lighting and homogeneous thermal barrier by the same device	Non-effective lighting, thermal barrier or both	Dimensions of triangular base / shape of diffuser / properties of cover light optic
Non-required lighting in summer days	Destroying crops with high radiation	Use only cooling function (fans & pump) and energy storage (batteries etc.)

12 DISCUSSION

The only needed software regulation must measure the ambient temperature and detect the presence of humans and fire. For this reason, it is advantageous to apply the thermovision technology that can easily detect robots. In industry they are expected to be more and more deployed. With this monitoring system their activity can be better controlled. The power of heating/cooling and lighting conditions for them can be interactively adapted. Since the device has its own blowing element, it is possible to expect addition energy savings on interactive regulation of all provided conditions. Savings depend on the occupancy of people/robots, so the industry's operating costs can fully copy production levels and the level of automation.

The economic analysis must be adapted in the case of fresh air operation, also with the additional elements on the device. For greenhouse applications, a comparison of investments can’t count a heat distribution end-elements. On the other side, we can calculate higher crop production, especially in winter, when the price of fruit and vegetables is higher in the market. So, a more complicated, expensive but multifunctional solution has a chance to be a "cheaper" solution at the end of the day.

The heat pump and solar technology represent the main renewable technologies for the best cooperation with the presented system. Preheating by waste heat increases energy savings and decrease payback time of investment. It is not excluded that a direct connection (DC current) with a photovoltaic panel can contribute to future performance. As can be seen from this article, multifunctionality in buildings with a higher level of energy efficiency is possible thanks to utilization of waste heat from artificial light sources, as shown in Fig. 15.

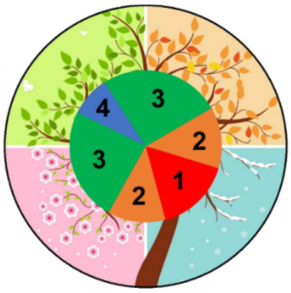


Fig. 15. Year-round operation with generated waste heat from LED light sources.
1 – Preheating for boiler or heat pump/thermal barrier, 2 – Heating/thermal barrier
3 – Hot water preparation, 4 – Removing from the space

13 CONCLUSION

The global energy trend is focuses attention on RES application. Since the presented multifunction system jointly works with electrical and thermal energy, it supports the application of all scope of RES, especially in case of Demand and Response feature. Applications of solar technologies increase the thermal power utilization of the natural light source – Sun. This is the best argument for inspiring the research and development on utilization of the thermal power of artificially light sources, especially if the dimmable and energy efficient LED light source with long operating lifetime is affordable on the market.

It seems, the new Multifunctional Energy System with LED source “MESLED” is the most advantageous for the user. With just one multifunction technical system it doesn’t need the project management of more several technologies during construction. It saves also the time not just in realization but also in operation thanks to merged maintenance. The described “MESLED” system represents the new way how to maximize the usage time of technical system invested on, especially if human (fire) safety can be higher than today. In the case of currently used solution (LED luminaire - passive cooling method) the waste heat generated from lighting is not used, therefore it cannot guarantee the maximum possible energy efficiency of the so-called “Green Building”.

As the electricity consumption and the production of electricity from renewable energy sources is unpredictable at time, the efficient Demand and Response element is more than important to produce low-carbon electricity in future (creating Smart and Micro Grids). The described multifunctionality in greenhouses meets the basic needs of the growing population - Food & Energy. Of course, the light creates a strong link between them, since the energy can’t be consumed, it can only be converted to the other form.

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