
APPENDIX 4

INSTRUCTIONS

FOR DETERMINING SAVINGS OF ENERGY FOR PUBLIC LIGHTING

TITLE OF THE CONTRACT: CONTRACT ON ENERGY SERVICE FOR IMPLEMENTATION OF ENERGY EFFICIENCY IMPROVEMENT MEASURES AND SAVINGS IN OPERATING COSTS OF PUBLIC LIGHTING

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1 INTRODUCTION TO MEASUREMENT AND VERIFICATION

The public lighting system generally consists of the following main parts:

1. Supply grid (including substations)
2. Connection points (usually posts)
3. Luminaires/Lamps (including ballasts)
4. Remote control unit (in applicable cases only).

For an energy efficiency project, the third item of the list is the most relevant, while all four items are related to maintenance issues.

Since the system is as simple as described above, determination of energy consumption in public lighting can be based on calculations of installed power rather than on measurements. Measurements are not always available or the number of lamps out of operation is not known, or the additional consumption by users connected to the grid, who, in terms of law, are unauthorized consumers of electricity, may increase measured consumption. For determining savings in energy consumption based on installed power, the rate of the functioning lamps (LF) - as set for the calculation of costs in the Baseline Period - must be constant.

Energy savings may further be increased by an agreed upon reduction of the illuminance level or by completely switching off parts of the public lighting system for a certain period of time during the night. Both measures must be fully reflected in the calculations.

Savings in maintenance costs depend on the required level of maintenance in relation to the same level of maintenance in the past, namely the costs of lamp replacement and cleaning. In cases where maintenance procedures in the past did not achieve the same level of quality as stipulated by this Contract, the maintenance costs in the Baseline Period should be re-calculated and adjusted to the required level of quality performance (LF).

2 LIST OF PARAMETERS

The following Table includes the list of parameters (variables) relevant for the Monitoring and Verification of savings in the operating costs for public lighting projects

Most frequently used acronyms in the text that follows:

BR = Baseline Period)

GR = Guarantee Period

(p.a.) = per annum

Table 3: Overview of the relevant parameters

Variable	Unit	Description	Source
CEBa	€/a	Energy cost p.a., BP, all lamps, calculated based on consumption p.a. and reference price.	Equation no. 5
CEGa	€/a	Energy costs p.a., GP, all lamps, based on energy consumption p.a. and reference price.	Equation no. 15
CHML	[€/h]	Cost of labor per hour Cost for maintenance staff (lamp replacement)	Tender documentation: The Client should decide between two options: Table 3 or values from a maintenance contract signed following public procurement procedure in the last two years before the publication of the tender for energy efficiency improvement services. In case of selecting the latter option, the costs will be calculated in EUR using the official exchange rate of the National Bank of Serbia on the date of signature of the maintenance contract.
CHMM	[€/h]	Cost of renting a lift truck per hour, necessary to	Comment same as in the row above

Variable	Unit	Description	Source
		replace lamps (or components)	
CMAT,i	€	Cost of material for one lamp of type *i*	Comment same as in the row above
CMBa	€/a	Total annual costs of maintenance, for all lamp types, for establishing BP maintenance costs	Equation no. 9
CMBa,i	€/a	Average costs of maintenance p.a. for one lamp of type *i*, for establishing BP maintenance costs	Equation no. 6
COBa	€/a	Total annual operating costs for all lamp types, in BP	Equation no. 10
CSEGa	€/a	Cost-savings for energy p.a. in the GP Difference in the energy costs p.a. in BP and GP	Equation no. 16
CSMGa	€/a	Cost-savings for maintenance p.a. in GP	Contractor's Bid (Appendix 4)
CSOPa	€/a	Savings in total operating costs p.a. in GP	Equation no. 17
CXa,i	€/a	Replacement costs p.a. for one lamp of type *i*	Equation no. 8
EBa	MWh/a	Energy consumption p.a., all lamps, in BP	Equation no. 4
EBFa	MWh/a	Energy consumption p.a., lamps in full operation all night, BP	Equation no. 1
EBOa	MWh/a	Energy consumption p.a., lamps switched off part of the night, BP	Equation no. 2
EBRa	MWh/a	Energy consumption p.a., lamps with reduced power part of the night, BP	Equation no. 3
EGa	MWh/a	Energy consumption p.a., all lamps, GP	Equation no. 4

Variable	Unit	Description	Source
EGFa	MWh/a	Energy consumption p.a., lamps in full operation all night, GP	Equation no. 11
EGOa	MWh/a	Energy consumption p.a., lamps switched off part of the night, GP	Equation no. 12
EGRa	MWh/a	Energy consumption p.a., lamps with reduced power part of the night, GP	Equation no. 13
EPr	€/MWh	Reference energy price	Tender documentation
HBF,i	h/a	Operating hours p.a. of lamp type i, fully operating all night, BP	Prescribed by the Municipality in the tender documentation (Appendix 2). No. of operating hours may not be below 4,100 hours per year
HBO,i	h/a	Operating hours p.a. of lamp type *i*, switched off for part of the night, BP	Prescribed by the Municipality in the tender documentation (Appendix 2).
HBR,i	h/a	Operating hours p.a. of lamp type *i*, with reduced power for part of the night, BP	Prescribed by the Municipality in the tender documentation (Appendix 2).
HGF,i	h/a	Operating hours p.a. of lamp type *i*, fully operating all night, GP	Prescribed by the Municipality, should be the same as HBF,i
HGO,i	h/a	Operating hours p.a. of lamp type *i*, switched off for part of the night, GP	Contractor's Bid (Appendix 3)
HGR,i	h/a	Operating hours p.a. of lamp type *i*, with reduced power for part of the night, GP	Contractor's Bid (Appendix 3)
HX	[h]	Average time required to replace one lamp including other components	Tender documentation: The Client should decide between two options: Table 3 or values from a maintenance contract signed following public

Variable	Unit	Description	Source
			procurement procedure in the last two years before the publication of the tender for energy efficiency improvement services. In case of selection of the latter option, the costs will be calculated in EUR using the official exchange rate of the National Bank of Serbia on the date of signature of the maintenance contract
i	-	"i" stands for a specific lamp type, which includes lamp technology and nominal lamp power	For the BP: Appendix 2 For the GP: Contractor's Bid (Appendix 3)
LF	-	Contracted rate of lamps functioning. The Rate of "Lamps Functioning" is used as quality performance criterion as requested by the Client. The same LF rate shall be used both for BP and savings calculation in GP.	Tender documentation
Li	W	Lamp type *i*, nominal power	Nominal lamp power taken from lamp manufactures' specification For the BP: Appendix 2 For the GP: Contractor's Bid (Appendix 3)
LLi	W	Lamp type *i*, power loss of ballast	Power loss taken from luminaire manufactures' specification[15] For the BP: Appendix 2 For the GP: Contractor's Bid (Appendix 3)
LR,i	W	Reduced power of lamp type *i* at reduced illuminance level, in case reduction of illuminance is applied	Reduced lamp power taken from manufactures' specification related to the unit for illuminance reduction control device. For the BP: Appendix 2 For the GP: Contractor's Bid (Appendix 3)
LT,i	h	Nominal lifetime for lamp type *i*	1) For the lamps in the BP: Tender documentation: The Client should decide between two options

Variable	Unit	Description	Source
			manufacturer's specification or Table 2. 2) For the lamps replaced within the project: Contractor's Bid / Manufacturer's specification.
LXBF,i	1/a	Frequency of replacement per year of lamp type *i*, fully operating all night, BP. Frequency of replacement depends on lifetime of lamp type *i*.	Equation no. 7
LXGF,i	1/a	Frequency of replacement per year lamp type *i*, fully operating all night, GP. Frequency of replacement depends on lifetime of lamp type *i*.	Equation no. 7
NL	number	Total number of lamps in the system	Appendix 2 and the Contractor's Bid (Appendix 3)
NLB,i	number	Number of lamps of type *i* in the system, BP	Appendix 2
NLBF,i	number	Number of lamps of type *i* in the system operating full time all night, BP	Appendix 2
NLBO,i	number	Number of lamps of type *i* in the system switched off for part of the night, BP	Appendix 2
NLBR,i	number	Number of lamps of type *i* in the system operating with reduced power for part of the night, BP	Appendix 2
NLG,i	number	Number of lamps of type *i* in the system, GP	Contractor's Bid (Appendix 3)
NLGF,i	number	Number of lamps of type *i* in the system operating full time all night, GP	Contractor's Bid (Appendix 3)
NLGO,i	number	Number of lamps of type *i* in the system switched off	Contractor's Bid (Appendix 3)

Variable	Unit	Description	Source
		for part of the night, GP	
NLGR,i	number	Number of lamps of type *i* in the system operating with reduced power for part of the night, GP	Contractor's Bid (Appendix 3)
TB	number	Number of different lamp types *i* in the system, BP	Appendix 2
TG	number	Number of different lamp types *i* in the system, GP	Contractor's Bid (Appendix 3)

[15] If power loss of ballasts is unknown, power loss should be calculated as 15% of the nominal power of a lamp.

3 ESTABLISHING OF COSTS IN THE BASELINE PERIOD

3.1 ENERGY CONSUMPTION AND ENERGY COSTS IN THE BASELINE PERIOD

All the following explanations refer to the municipal Public Lighting System (PLS), as identified by the project boundary, for which the Contract on Energy Efficiency Improvement will be concluded. This PLS consists of a number of lamps (NL), which is assumed to be equal in the Baseline Period (BP) and in the Guarantee Period (GP):

Definition 1

$$NL = NLB = NLG$$

The energy consumption for both periods can be determined based on the installed power multiplied by operating hours.

While the total number of lamps (NL) remains constant, the Contractor shall change the structure of the PLS by replacing inefficient lamp types by lamps with a lower specific power consumption.

The structure of the old PLS is described by the composition of old lamp types, whereby the number of different lamp types used in the Baseline Period is marked with TB. The structure of the new PLS is described by the composition of new lamp types, whereby the number of different lamp types used in the Guarantee Period is marked with TG:

Definition 2

$$NLB = \sum_{i=1}^{TB} NLB,i \implies NLG = \sum_{i=1}^{TG} NLG,i$$

The PLS in the Baseline- and in the Guarantee Period may also differ – depending on each individual case – in a way in which different types of lamps are used:

- Number of lamps, which operate full night: $NLBF,i \Rightarrow NLGF,i$
- Number of lamps, which are switched off for parts of the night: $NLBO,i \Rightarrow NLGO,i$
- Number of lamps, which operate with reduced power for parts of the night: $NLBR,i \Rightarrow NLGR,i$

Commonly, total operating hours range around 4.100 h per year in the Republic of Serbia, whereby the period in which PL is switched off is around 2.190 h (e.g. in the interval

between 23:00 and 05:00). Operating hours in different operating modes may vary due to the use of different lamp types and may also be different in the Baseline and in the Guarantee Period.

The energy consumption, in the Baseline Period, of all types of lamps that operate the whole night expressed in (kWh/a) is calculated in the following way:

Equation no. 1

$$EBFa = LF/100 \times \sum_{i=1}^{TB} NLBF,i\ (Li + LLi) HBF,i$$

If, in the Baseline Period, lamps are switched off for parts of the night, the related Baseline energy consumption of all types of lamps, expressed in (kWh/a) is calculated as follows:

Equation no. 2

$$EBOa = LF/100 \times \sum_{i=1}^{TB} NLBO,i\ (Li + LLi)\ (HBF,i\ -\ HBO,i)$$

If, in the Baseline Period, the illuminance level is partly reduced for parts of the night, the related energy consumption of all types of lamps, expressed in (kWh/a) is calculated as follows:

Equation no. 3

$$EBRa = LF/100 \times \sum_{i=1}^{TB} NLBR,i\ [(Li + LLi)\ (HBF,i - HBR,i) +\ (LR,i + LLi)\ HBR,i]$$

The total energy consumption (EBa) of the public lighting system in the Baseline Period is the sum of energy consumptions of all lamp types operating in different regimes in the Contracted Facility (see Appendix 2):

Total Baseline Period energy consumption is calculated as follows:

Equation no. 4

$$EBa = EBFa + EBRa + EBOa$$

To calculate the Energy Cost Baseline (CEBa) the energy consumption in the Baseline Period has to be multiplied by the Reference Energy Price (EPr):

Equation no. 5

$$CEBa = EBa \times EPr$$

3.2 MAINTENANCE COSTS IN THE BASELINE PERIOD

To establish the maintenance costs in the Baseline Period, the level of maintenance characterized by the quality performance indicator – the rate of functioning lamps, should be set at the same level. For the calculation of the Baseline maintenance costs, a maintenance schedule with regular lamp replacement according to the nominal lifetime of the lamps and other components is prescribed.

For the purpose of calculating the maintenance costs, the following lifetime values are provided.

Table 1: Lifetime of different lamps

Technology	Lifetime (LT) [h]
Incandescent	1,000-1,500
HPM – High Pressure Mercury	6,000-8,000
HPS – High Pressure Sodium	16,000

The most relevant in terms of possible savings in the maintenance costs are the costs of lamp and spare parts replacement and cleaning. These costs contain costs of materials (lamps and spare parts) disposal costs, labour costs, and costs for required vehicles. Lamp replacement depends on the lifetime of the lamps, which again depends on lamp technology. Cleaning cycles usually depend on the location (inner city, high pollution) but are commonly combined with lamp replacement for economic reasons.

The typical time (HX), which is required for a lamp replacement ranges between 15 minutes (if the post and luminaire are easily accessible) and 30 minutes (if post is high, and lamp moderately accessible). In most cases a lift truck is required. Based on a conservative assessment, 30 minutes is taken as reference time required to replace a lamp and it is shown in Table 5.

To calculate the costs of replacement of one lamp of type *i* in the Baseline Period, the following cost categories have to be taken into account:

- Labour costs: CHML [€/h]
- Costs of lift truck CHMM [€/h]
- Material costs (lamps per type): CMAT,i [€]

Consequently, the costs for replacement of one lamp of type *i* amount to:

Equation no. 6

$$CMBa,i = CHML \times HX + CHMM \times HX + CMAT,i$$

$$CMBa,i = (CHML + CHMM) \times HX + CMAT,i$$

If applicable, additional costs of disposal of lamps have to be included in those costs, or to be added in this equation.

This calculation is also valid for replacement of other spare parts. In that case, the costs of spare parts have to be added to the costs of materials CMBa,i.

Table 5: Values for the maintenance parameters for the Baseline Period

Parameter	Description	Value
HX [h]	Average time needed for maintenance of one lamp	0.5
CHML [€/h]	Costs of labour per hour	7
CHMM [€/h]	Costs of lift truck per hour	25
CMAT,i [€/pcs]	Material cost mix per one lamp of type i (lamp + socket + glass + ballast + fixture)*	
	Incandescent 100/E27	0.6
	Incandescent 200/E27	1.2
	Incandescent 300/E40	2.6
	HPM 80/E27	2.6
	HPM 125/E27	3.0
	HPMmix160/E27	3.8
	HPM 250/E40	6.1
	HPM 400/E40	8.7
	HPM 700/E40	9.8

* Different lifetimes of lamp components are taken into account and brought down to the lifetime of the lamp

To achieve reliable functioning of the system as well as a good light quality, lamps have to be replaced frequently. The frequency of lamp replacement per year depends on the lifetime of lamps and the operating hours per year.

Equation no. 7

Full operation all night	LXBF,i = HBF,i/LT,i
Switched off for part of the night	LXBO,i = HBO,i/LT,i

Reduced power for part of the night	For the frequency of replacement-calculation, lamps with reduced power for parts of the night are treated equal to lamps in full operation all night: LXBR,i = LXBF,i

Consequently, the annual maintenance costs CXa,i for all lamps ($NLB_{,i}$) of lamp type i amount to:

Equation no. 8

$$CXa,i = NLBF,i \times LXBF,i \times CMBa,i + NLBO,i \times LXBO,i \times CMBa,+ NLBR,i \times LXBF,i \times CMBa$$

$$CXa,i = CMBa,i\ (NLBF,i \times LXBF,i + NLBO,i \times LXBO,i + NLBR,i \times LXBF,i)$$

The total annual maintenance costs, i.e. the Baseline for maintenance costs (CMBa) are the sum of all lamp types used in the Baseline Period:

Equation no. 9

$$CMBa = LF/100 \times \sum_{i=1}^{TB} CXa,i$$

where TB corresponds to the number of different lamp types in the old PLS.

3.3 OPERATINNG COSTS IN THE BASELINE PERIOD

The annual operating cost Baseline is calculated as the sum of both types of Baselines above:

Equation no. 10

$$COBa = CEBa + CMBa$$

4 SAVINGS VERIFICATION

Purpose of an energy efficiency project is to reduce operating costs for the public lighting system.

If changes in the usage of the public lighting system have occurred, such changes have to be taken into account.

4.1 REDUCTION OF ENERGY CONSUMPTION

The reduction in energy consumption will be achieved by higher efficiency in system operation – mainly by more efficient components like new lamps, luminaires and ballasts. However, a pre-condition for the application of new components is that the lighting quality is at least maintained. If illuminance level was not satisfactory before, it is expected to be improved. In cases where the illuminance level is very high – even higher than the one defined in the standards – the client and the contractor could agree on a reduction of illuminance level in order to achieve additional savings (see Appendix 6).

To calculate the energy savings, the new annual energy consumption in the Guarantee Period (EGa) is calculated analogously to Equations Nos. 1-4 from Chapter 3.1, but with the new lamp types installed and with the number of operating hours per year in the Guarantee Period (HGF,i, HGR,i and HGO,i respectively):

The energy consumption in the Guarantee Period by all types of lamps operating the whole night, expressed in (kWh/a) is calculated as follows:

Equation no. 11

$$EGFa = LF/100 \times \sum_{i=1}^{TG} NLGF,i\ (Li + LLi)\ HGF,i$$

where usually HBF,i = HGF,i.

If the partial switching off is implemented in the Guarantee Period, the energy consumption in the Guarantee Period by all types of lamps that are partially switched off, expressed in (kWh/a) is calculated as follows:

Equation no. 12

$$EGOa = LF/100 \times \sum_{i=1}^{TG} NLGO,i\ (Li + LLi)\ (HGF,i\ - HGO,i)$$

If a reduction of the illuminance level is implemented in the Guarantee Period, the energy consumption in the Guarantee Period by all types of lamps that partially operate with reduced power, expressed in (kWh/a) is calculated as follows:

Equation no. 13

$$EGRa = LF/100 \times \sum_{1}^{TG} NLGR,i\,[(Li + LLi)(HGF,i - HGR,i) + (LR,i + LLi)HGR,i]$$

The total energy consumption of the public lighting system in the Guarantee Period (EGa) is the sum of energy consumption by all lamp types operating in different regimes in the Contracted Facility (see Appendix 2):

Total annual energy consumption during the Guarantee Period is calculated as follows:

Equation no. 14

$$EGa = EGFa + EGOa + EGRa$$

To calculate annual Energy Cost in the Guarantee Period (CEGa), the energy consumption in the Guarantee Period has to be multiplied by the Reference Energy Price (EPr):

Equation no. 15

$$CEGa = EGa \times EPr$$

The savings in energy costs for the year in question is the difference between the energy cost Baseline and the energy cost in the Guarantee Period:

Equation no. 16

$$CSEGa = CEBa - CEGa$$

4.2 REDUCTION OF MAINTENANCE COSTS

Savings in maintenance costs (CSMGa) are taken from the Bid of the contractor (Appendix 3).

The level of maintenance has to include at least:

- Replacement of the non–functioning lamps within the contractual period within the time limit specified in the tender documentation. The rate of functioning of lamps (LF) has to be at all times equal to or higher than the agreed value;

- Carrying out of regular inspections or touring to control the functioning of the public lighting system in the Contracted Facility at the frequency agreed and including documenting the tours;
- Regular reporting to the municipality on the number of reported faults at the frequency agreed.

(see Appendix 6)

4.3 ANNUAL SAVINGS IN OPERATING COSTS

The savings in operating costs represent the sum of both types of achieved savings, the savings in energy costs and the savings in maintenance costs:

Equation no. 17

$$CSOPa = CSEGa + CSMGa$$