OptiSave Savings Calculator — Calculation Method

Prototype method reference · SI units throughout

Abstract. This note documents how the OptiSave savings calculator converts vessel data into an annual fuel, cost and emissions saving, and a payback time, for frequency converters (VSDs) fitted to the sea-water and fresh-water cooling pumps, the auxiliary boiler feed-water pumps and the engine-room fans. Every quantity is evaluated separately for the vessel in port and at sea and the two are summed. Pump and fan shaft power is reduced by the affinity laws [5] or a linear flow-reduction factor; electrical energy is converted to genset fuel through a mix-corrected specific fuel consumption [1, 2]; emissions follow the IMO carbon factors [3] and the MARPOL Annex VI NO_x curve [4]. Results are checked against the manufacturer reference calculations [6].

1 Structure and conventions

Every quantity is computed *twice* — once for the vessel *in port* and once *at sea* — because seawater temperature, engine load and fuel differ between the two. Each mode carries its own operating hours, fuel mix, genset SFOC and per-pump parameters; the annual result is the sum of the two modes.

Four auxiliary groups are modelled, each with a fixed-speed *baseline* (no OptiSave) and a variable-speed *OptiSave* operating point:

Sea-water (SW) cooling pumps
heat balance and affinity laws; speed floored by the VSD minimum frequency.

Fresh-water / low-temperature (FW/LT) cooling pumps
affinity to a load factor (the manufacturer simultaneous factor).

Auxiliary boiler feed-water pumps
same model as FW/LT; load factor back-fitted to the reference summary.

Engine-room supply fans
linear flow-reduction; power proportional to flow.

Internally all quantities are SI (`W, Pa, m³/s, K, h`); interface values are converted on entry (`m³/h, kW, bar, mbar, %`). SFOC is kept in `g/kWh`. Speed ratios use f_{min}/f_{ref} in Hz, where f_{ref} is the ship supply frequency and the reference speed for every VSD. The sailing profile is entered as hours per year or as a percentage of an 8760 h year (switching converts both); each mode's load is applied for its own hours.

2 Baseline electrical power

Without OptiSave the rotodynamic auxiliaries run at fixed speed at their rated duty point. Rated flow, power and head are specified *per pump*. For the pump groups,

$$P_{\mathrm{ref}} = P_{\mathrm{rated}}\, n_{\mathrm{run}} \tag{1}$$

and for the engine-room fans,

$$P_{\mathrm{ref}} = \frac{\dot{V}_{\mathrm{ref}}\, \Delta p_{\mathrm{fan}}}{\eta_{\mathrm{fan}}} \tag{2}$$

P_{rated}	rated shaft / motor power per pump [kW]
n_{run}	pumps running in the mode [–]
$\dot{V}_{ref}$	design air flow, all fans [m^3/s]
Δp_{fan}	fan static pressure rise [Pa]
η_{fan}	combined fan + motor efficiency [–]

The baseline electrical load of a mode is the sum over the four groups, $P_{ref,elec} = \Sigma P_{ref}$.

3 OptiSave electrical power

A frequency converter lets each machine run only as fast as demand requires. Three sub-models follow.

3.1 Sea-water cooling pumps

The heat the central coolers must reject is the installed (design) capacity scaled by a heat-load factor,

$$Q = Q_{design}\,\varphi \tag{3}$$

The seawater flow that holds the target cooler-outlet temperature follows from an energy balance,

$$\dot{V}_{need} = \frac{Q}{\rho\, c_p\,(T_{out,tgt} - T_{in})} \tag{4}$$

The pump speed ratio is that flow demand, bounded below by the VSD minimum frequency and above by full speed,

$$s_{flow} = \dot{V}_{need} / \dot{V}_{ref}, \quad s_{min} = f_{min} / f_{ref} \tag{5}$$

$$s = \min(1, \max(s_{flow}, s_{min})) \tag{6}$$

> The manufacturer CSW reference calculation [6] uses $f_{min} \approx 33$ Hz ($s_{min} \approx 0.55$ on a 60 Hz supply), set by the minimum system pressure the circuit must hold.

The affinity laws [5] then carry flow, head and power off the rated point,

$$\dot{V}_{opt} = s\,\dot{V}_{ref}, \quad H_{opt} = s^2\,H_{ref}, \quad P_{opt} = s^3\,P_{ref} \tag{7}$$

and the cooler-outlet temperature is recovered from the same balance for either flow ($\dot{V}_{ref}$ or $\dot{V}_{opt}$),

$$T_{out} = T_{in} + \frac{Q}{\rho\, c_p\,\dot{V}} \tag{8}$$

> *Limited by* in the results: `design` (full speed), `min Hz` ($s_{min} > s_{flow}$), or the target outlet temperature otherwise.

Q_{design}	installed cooler capacity [W]
ϕ	heat-load factor [–]
$\rho\ c_p$	coolant density × specific heat [J/(m^3·K)]
$T_{out,tgt}$	target cooler-outlet temperature with OptiSave [°C]
T_{in}	mean actual seawater inlet temperature [°C]
$\dot{V}_{ref}$	rated flow × pumps running [m^3/s]
H_{ref}	rated pump head [Pa]
f_{min}, f_{ref}	VSD minimum / ship supply frequency [Hz]

3.2 Fresh-water and boiler-feed pumps

For the closed loops the manufacturer *simultaneous factor* λ is the OptiSave power fraction directly. Through $P \propto s^3$ the corresponding speed is its cube root,

$$s_{\mathrm{load}} = \lambda^{1/3}, \quad s = \min(1, \max(s_{\mathrm{load}}, f_{\mathrm{min}}/f_{\mathrm{ref}})) \tag{9}$$

$$\dot{V}_{\mathrm{opt}} = s\,\dot{V}_{\mathrm{ref}}, \quad H_{\mathrm{opt}} = s^2\,H_{\mathrm{ref}}, \quad P_{\mathrm{opt}} = s^3\,P_{\mathrm{ref}} = \lambda\,P_{\mathrm{ref}} \tag{10}$$

The last equality holds while s_{load} binds (`load factor`); the minimum-frequency floor overrides it at very low load (`min Hz`).

3.3 Engine-room fans

$$\dot{V}_{\mathrm{opt}} = \dot{V}_{\mathrm{ref}}(1 - k), \quad P_{\mathrm{opt}} = \dot{V}_{\mathrm{opt}}\,\Delta p_{\mathrm{fan}} \,/\, \eta_{\mathrm{fan}} = (1 - k)\,P_{\mathrm{ref}} \tag{11}$$

k = flow reduction with OptiSave [–]. Power scales linearly with flow (no affinity roll-off), matching the construction of the manufacturer fan sheet [6].

Mode totals are $P_{\mathrm{opt,elec}} = \Sigma\ P_{\mathrm{opt}}$ and the electrical power saved is $\Delta P_{\mathrm{elec}} = P_{\mathrm{ref,elec}} - P_{\mathrm{opt,elec}}$.

4 Annual electrical energy

Each mode's power is held for its operating hours h,

$$E = P_{\mathrm{elec}}\,h \,/\, 1000, \quad \Delta E = \Delta P_{\mathrm{elec}}\,h \,/\, 1000 \tag{12}$$

h = hours in the mode per year (in port, or at sea); E in kWh/yr.

5 Genset fuel

The genset SFOC is quoted against a reference fuel LHV (ISO 3046-1 / ISO 15550 [1, 2]: 42.7 MJ/kg). It is corrected to the mass-weighted LHV of the mode fuel blend, a lower-energy fuel requiring proportionally more mass per kWh,

$$\begin{gathered} LHV_{\mathrm{mix}} = \Sigma_{\mathrm{i}}\,x_{\mathrm{i}}\,LHV_{\mathrm{i}} \\ SFOC_{\mathrm{eff}} = SFOC \cdot LHV_{\mathrm{ref}} \,/\, LHV_{\mathrm{mix}} \end{gathered} \tag{13}$$

Fuel mass then follows from energy and the corrected SFOC,

$$\dot{m}_{\mathrm{fuel}} = E \cdot SFOC_{\mathrm{eff}} \,/\, 10^6, \quad \Delta\dot{m}_{\mathrm{fuel}} = \Delta E \cdot SFOC_{\mathrm{eff}} \,/\, 10^6 \tag{14}$$

g/kWh × kWh = g; ÷10^6 → tonnes. x_{i} is the mass fraction of fuel i ($\Sigma\,x_{\mathrm{i}} = 1$).

6 Cost and emissions saved

The saved fuel mass is valued and converted to emissions with the same mass-weighted blend,

$$\bar{c} = \Sigma_{\mathrm{i}}\,x_{\mathrm{i}}\,c_{\mathrm{i}}, \quad \bar{e} = \Sigma_{\mathrm{i}}\,x_{\mathrm{i}}\,EF_{\mathrm{i}}, \quad \bar{s} = \Sigma_{\mathrm{i}}\,x_{\mathrm{i}}\,S_{\mathrm{i}} \tag{15}$$

$$\begin{gathered} \Delta C = \Delta\dot{m}_{\mathrm{fuel}}\,\bar{c}, \quad \Delta m_{CO_2} = \Delta\dot{m}_{\mathrm{fuel}}\,\bar{e} \\ \Delta m_{SO_2} = \Delta\dot{m}_{\mathrm{fuel}}\,(\bar{s}/100) \cdot 2 \end{gathered} \tag{16}$$

c_{i} fuel cost [USD/t]; EF_{i} CO_2 factor [t/t], IMO MEPC.245(66) [3]; S_{i} sulphur [mass %]; the factor 2 is the S → SO_2 molar-mass ratio (≈ 64/32). IFO380 exhaust is taken as scrubbed to a 0.1 % sulphur-equivalent ($S_{\mathrm{IFO380}} = 0.1$); other fuels use their stated sulphur.

NO_x is taken from the genset certified limit rather than the fuel — MARPOL Annex VI Reg. 13 [4], a function of rated genset speed n [rpm] and tier (Tier III only inside a NO_x ECA). For $130 \le n < 2000$,

$$L_{\mathrm{NOx}} = 45n^{-0.20}\ \text{(I)},\quad 44n^{-0.23}\ \text{(II)},\quad 9n^{-0.20}\ \text{(III)}\quad \text{[g/kWh]} \tag{17}$$

$$\Delta m_{\mathrm{NOx}} = \Delta E \cdot L_{\mathrm{NOx}} / 10^6 \tag{18}$$

Applied to the saved electrical energy ΔE [kWh]; the tier is chosen per mode.

7 Economics

Port and sea annual figures are summed: $\Delta C_{\mathrm{yr}} = \Delta C_{\mathrm{port}} + \Delta C_{\mathrm{sea}}$ (likewise ΔE, $\Delta \dot{m}_{\mathrm{fuel}}$, $\Delta m_{\mathrm{CO_2}}$, $\Delta m_{\mathrm{SO_2}}$, Δm_{NOx}).

The cash flow is a running balance. The year-y saving grows at the fuel-price inflation rate r,

$$S_{\mathrm{y}} = \Delta C_{\mathrm{yr}}\,(1 + r)^{y-1} \tag{19}$$

and the balance opens at $-I$ and each year accrues interest at the cost-inflation rate c before the saving is added,

$$B_0 = -I,\quad B_{\mathrm{y}} = B_{\mathrm{y-1}}(1 + c) + S_{\mathrm{y}} \tag{20}$$

with I = CAPEX + installation cost. The cash-flow curve is $\{B_{\mathrm{y}}\}$. Payback is the first year the balance is non-negative, linearly interpolated,

$$t_{\mathrm{pb}} = (y - 1) + (-B_{\mathrm{y-1}}) / (B_{\mathrm{y}} - B_{\mathrm{y-1}}) \tag{21}$$

$$\text{net position} = B_{\mathrm{N}},\quad \mathrm{ROI} = 100\, B_{\mathrm{N}} / I\quad [\%] \tag{22}$$

N = evaluation horizon [yr]. Both rates move the payback. There is no payback when the balance never turns positive — fuel deflation ($r < 0$) that caps the savings, or cost inflation (c) that compounds the outstanding balance faster than the savings repay it.

8 Worked example: SW pumps in port

The step that most exercises the model. Inputs are the reference-vessel defaults that seed the calculator.

> 1. Heat load, Eq. (3): `Q = 9311 × 0.5 = 4656 kW`
> 2. $\rho\ c_p$ `= 1000 × 4190 = 4.19×10⁶ J/(m³·K)`; `ΔT = 48 − 22 = 26 K`
> 3. Flow, Eq. (4): $\dot{V}_{need}$ `= 4.656×10⁶ / (4.19×10⁶ × 26) = 0.0427 m³/s ≈ 154 m³/h`
> 4. $\dot{V}_{ref}$ `= 2 × 400 = 800 m³/h` → s_{flow} `= 0.19`
> 5. Eq. (5)–(6): s_{min} `= 33/60 = 0.55` → `s = 0.55` (minimum frequency binds)
> 6. Baseline, Eq. (1): P_{ref} `= 2 × 40.7 = 81.4 kW`
> 7. OptiSave, Eq. (7): P_{opt} `= 0.55³ × 81.4 = 13.5 kW`
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>
> `This tool:` **`81.4 → 13.5 kW`** `| manufacturer CSW pump-curve sheet [6]:` **`81.4 → 13.52 kW`**

9 Validation against the reference calculations

SYSTEM	BASELINE	ANNUAL SAVING	VS. REF. [6]
SW cooling pumps	713 MWh/yr	595 MWh/yr	+11 %
FW/LT cooling pumps	557 MWh/yr	279 MWh/yr	exact
Boiler feed pumps	477 MWh/yr	262 MWh/yr	exact
Engine-room fans	508 MWh/yr	292 MWh/yr	exact

- **SW pumps, +11 %.** The reference CSW sheet counts the with-OptiSave seagoing hours as 8760 rather than 4380; on a consistent basis its own 13.5 kW figure reproduces 595 MWh/yr, so the gap is the hours, not the model.
- **Boiler feed pumps.** No standalone reference sheet; the port/sea load-factor split is set so the annual total matches the reference summary.
- One design operating point per mode: no part-load efficiency roll-off, no transient or weather variation.
- The reference summary prices the whole saving at one fuel price; this tool prices the per-mode fuel mix, so payback differs when the in-port mix is MGO-heavy.
- Fuel-price inflation r and cost inflation c default to 0; default CAPEX is the reference "parts only" figure, installation cost 0.
- Prototype for interface and logic review ahead of a compiled port; the core is one pure `calc(inputs) → outputs` function.

References

[1] ISO 3046-1, *Reciprocating internal combustion engines — Performance — Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods*. International Organization for Standardization.

[2] ISO 15550, *Internal combustion engines — Determination and method for the measurement of engine power — General requirements*. International Organization for Standardization.

[3] IMO Resolution MEPC.245(66), *2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships*, as amended — fuel carbon factors C_F.

[4] IMO, *MARPOL Annex VI, Regulation 13 — Nitrogen Oxides (NO_x)*, with the NO_x Technical Code 2008.

[5] Affinity (similarity) laws for centrifugal pumps and fans: flow ∝ speed, head ∝ speed^2, shaft power ∝ speed^3 at constant impeller diameter.

[6] Manufacturer OptiSave reference calculations for the reference vessel: CSW pump-curve, LT/FW pump-curve and engine-room fan-curve worksheets, and the project summary sheet.