Abstract

Although there has been considerable interest in innovative architectural and technical solutions for energy rehabilitation of housing, there has been less focus on environmental rehabilitation, which requires more rigorous processes and approaches to minimise environmental impact. This paper addresses this gap by evaluating the environmental performances of traditional Saharan single-family houses and contemporary European multi-family dwellings, in arid and oceanic-continental climates. The assessment was conducted using a multi-criteria indicator system based on a mathematical model and combining four impact categories (cumulative energy demand, resource depletion, greenhouse effect and smog), five indices (thermal, energy, environmental, morphological and metabolic) and four scenarios. The study indicates that the use of low-energy heating and air-conditioning (HVAC) systems and appropriate thermal zoning with insulated walls can reduce the heating demand of dwellings in oceanic-continental climates by 33.5% and 12% respectively. Additionally, the use of stone in the same climate can reduce the initial requirements of the baseline variant by up to 36.5%. The strategies employed ensured environmental optimization, along with a closed island morphology featuring offsets ranging from 0 to 45% from the reference. In arid climates, standard masonry optimized the energy performance of Saharan dwellings, reducing their heating needs by 31% and their cooling needs by 35%. This strategy, along with the patio and a closed island morphology, optimised their environmental performance, with reference offsets ranging from 0 to 41%. A tool has been developed to promote sustainable development in the built environment by enhancing codes and regulations for sustainable construction and rehabilitation operations.

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Ethics declarations

Conflict of interest

The authors declare that they have no known competing financial interests or relationships that could have appeared to influence the work presented in this paper.

Additional information

Publisher's Note

Appendices

Appendix

Appendix: A1

2.1 Characterization: Composite Sustainability Index

By integrating the composite index of Krajnc and Glavic (Krajnc & Glavič, 2005) from the AHP aggregation method, we obtained the following equation:

$$In=\sum in[WixCi]/\sum in[WixCi] \quad (4)$$

With:

I_n: Normalized indicator.

w_i: weighting coefficient of the criterion C_i of the indicator In corresponding to the impact n.

2.2 Normalization

We then assigned the normalization indices to our basic equation, we obtained the following equation:

$$In=(\sum in[WixCiR][ITRxIERxIMR]/IMetR)/((\sum in[WixCiV])[ITVxIEVxIMV]/IMetV) \quad (5)$$

With:

I_n: Normalized indicator.

w_i: weighting coefficient of the C_{iR} reference criterion of the I_n indicator corresponding to the impact n.

w_i: weighting coefficient of the criterion of the C_{iV} variant of the indicator I_n corresponding to the impact n.

I_{TR}/I_{TV}: Thermal normalization index of the reference/of the variant.

I_{ER}/I_{EV}: Energy normalization index of the reference/of the variant.

I_{MR}/I_{MV}: Morphological normalization index of the reference/of the variant.

I_{METR}/I_{METV}: Metabolic normalization index of the reference/of the variant.

By assigning the formulas for each normalization index, we obtain the following equation:

In=(∑in[WixCiR]∑in[(GRxVRxΔTR)x(EHRxFeH+EERxFeE)x(4πSRPR2)]/NURxNARxPmetR
∑in[WixCiV]∑in[(GVxVVxΔTV)x(EHVxFeH+EEVxFeE)x(4πSVPV2)]/NUVxNAVxPmetV)

(6)

With:

I_n: Normalized indicator.

w_i: Weighting coefficient of the C_{iR} reference criterion/ of the I_n indicator corresponding to the impact n.

w_i: Weighting coefficient of the criterion of the C_{iV} variant of the indicator I_n corresponding to the impact n.

G_R/G_V: Overall heat loss coefficient of the reference/of the variant (w/m^3.C°).

V_R/V_v: Volume of the reference/of the variant (m^3).

ΔTR/ΔTV: Temperature difference between outside and inside of the reference/of the variant (C°).
E_{HR}/E_{HV}: Winter energy requirements of the reference/of the variant (kwh/m^2).

F_{Eh}: Winter CO2 emission reference factor.

E_{ER}/E_{EV}: Summer energy requirements of the reference/of the variant (kwh/m^2).

F_{eE}: Summer CO2 emission reference factor.

S_R/S_V: Surface of the reference/of the building (m^2).

P_R/P_V: Perimeter of the reference/of the variant (m).

N_{UR}/N_{UV}: Number of users in the reference/in the variant.

N_{AR}/N_{AV}: Level of activity carried out by the users in the reference/in the variant (met).

P_{metR}/P_{metV}: Metabolic power released by the users of the reference/variant (Watt/kg).

2.3 Normalization factors

By assigning the factors values on which the normalization indices depend, we obtain the following equation:

In=(∑in[WixCiR]∑in[(GRxVRxΔTR)x(EHRx0.202+EERx0.680)x(4πSRPR2)]/NURx1.6x169∑in[WixCiV]∑in[(GVxVVxΔTV)x(EHVx0.202+EEVx0.680)x(4πSVPV2)]/NUVx1.6x169)

(7)

Weighting

By assigning the weighting value to the reference, we obtain:

In=(∑in[WixCiR]∑in[(GRxVRxΔTR)x(EHRx0.202+EERx0.680)x(4πSRPR2)]/NURx1.6x169∑in[WixCiV]∑in[(GVxVVxΔTV)x(EHVx0.202+EEVx0.680)x(4πSVPV2)]/NUVx1.6x169)

(8)

With:

w_i: Weighting coefficient of the C_{iR} reference criterion of the I_n indicator corresponding to the impact n.

w_i: Weighting coefficient of the criterion of the C_{iV} variant of the indicator I_n corresponding to the impact n.

G_R/G_V: Overall heat loss coefficient of the reference/of the variant (w/m^3.C°).

V_R/V_v: Volume of the reference/of the variant (m^3).

ΔTR/ΔTV: Temperature difference between outside and inside of the reference/of the variant (C°).

E_{HR}/E_{HV}: Winter energy requirements of the reference/of the variant (kwh/m^2).

E_{ER}/E_{EV}: Summer energy requirements of the reference/of the variant (kwh/m^2).

S_R/S_V: Surface of the reference/of the building (m^2).

P_R/P_V: Perimeter of the reference/of the variant (m).

N_{UR}/N_{UV}: Number of users in the reference/in the variant.

Appendix: A2

Final equations for each indicator are:

4.1 For an energy and environmental rehabilitation

- Principle of calculation of the cumulative energy demand indicator: I_{CDE}

$$ICDE=(\sum in[0.0039x20\% CiR]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(4\pi SRPR2)]/NURx1.6x169\sum in[0.0039xCiV]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(4\pi SVPV2)]/NUVx1.6x169) \quad (9)$$

- Principle of calculation of the resource depletion indicator: I_{RD}

$$IRD=(\sum in[20\% CiR/4500000000]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(4\pi SRPR2)]/NURx1.6x169\sum in[CiV/4500000000]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(4\pi SVPV2)]/NUVx1.6x169) \quad (10)$$

- Principle of calculation of the greenhouse effect indicator: I_{GHE}

$$IGHE=(\sum in[20\% CiRx1]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(4\pi SRPR2)]/NURx1.6x169\sum in[CiVx1]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(4\pi SVPV2)]/NUVx1.6x169) \quad (11)$$

- Principle of calculation of the smog indicator: Isg

$$ISg=(\sum in[20\% CiRx1]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(4\pi SRPR2)]/NURx1.6x169\sum in[CiVx1]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(4\pi SVPV2)]/NUVx1.6x169) \quad (12)$$

For sustainable reconstruction/ new design

- Principle of calculation of the cumulative energy demand indicator: I_{CDE}

$$ICDE=(\sum in[0.0039x20\% CiR]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(hv2/Sv)]/NURx1.6x169\sum in[0.0039xCiV]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(hR2/SR)]/NUVx1.6x169)$$

(13)

- Principle of calculation of the resource depletion indicator: I_{RD}

$$IRD=(\sum in[20\% CiR4500000000]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(hv2/Sv)]/NURx1.6x169\sum in[CiV4500000000]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(hR2/SR)]/NUVx1.6x169)$$

(14)

- Principle of calculation of the greenhouse effect indicator: I_{GHE}

$$IGHE=(\sum in[20\% CiRx1]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(hv2/Sv)]/NURx1.6x169\sum in[CiVx1]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(hR2/SR)]/NUVx1.6x169)$$

(15)

- Principle of calculation of the smog indicator: Isg

$$ISg=(\sum in[20\% CiRx1]\sum in[(GRxVRx\Delta TR)x(EHRx0.202+EERx0.680)x(hv2/Sv)]/NURx1.6x169\sum in[CiVx1]\sum in[(GVxVVx\Delta TV)x(EHVx0.202+EEVx0.680)x(hR2/SR)]/NUVx1.6x169)$$

(16)

With:

C_{IR}/C_{IV}: criterion i emitted or consumed by the reference/ by the variant.

G_R/G_V: Overall heat loss coefficient of the reference/of the variant (w/m^3.C°).

V_R/V_v: Volume of the reference/of the variant (m^3).

$\Delta TR/\Delta TV$: Temperature difference between outside and inside of the reference/of the variant (C°).

E_{HR}/ E_{HV}: Winter energy requirements of the reference/of the variant (kwh/m^2).

E_{ER}/ E_{EV}: Summer energy requirements of the reference/of the variant (kwh/m^2).

S_R/S_V: Surface of the reference/of the building (m^2).

P_R/P_V: Perimeter of the reference/of the variant (m).

h_R/h_v: Height of the reference/of the variant (m).

N_{UR}/N_{UV}: Number of users in the reference/in the variant.