Validation of ISO14N model

1. General Information

In this supplementary document the results of the verification procedure described in Paragraph 7.2, “Hourly method: verification cases”, of EN ISO 52016-1:2017 standard [1] are reported. In particular, temperature, load and energy need values obtained through the “ISO14N” model proposed by Lundström et al. [2] are compared to the corresponding values from EN ISO 52016-1:2017 spreadsheet tools, which are freely available from the EPB Center website [3]. As additional information, comparison with EnergyPlus [4] simulations is also reported for the hourly calculations.

2. Free Floating Cases

2.1. Operative Temperature

The comparison between the hourly operative temperatures simulated with the three simulation tools is excellent in the case of lightweight buildings and good in the case of heavyweight building. This can be observed qualitatively in the reference 4th January day (Figures S1–S2).

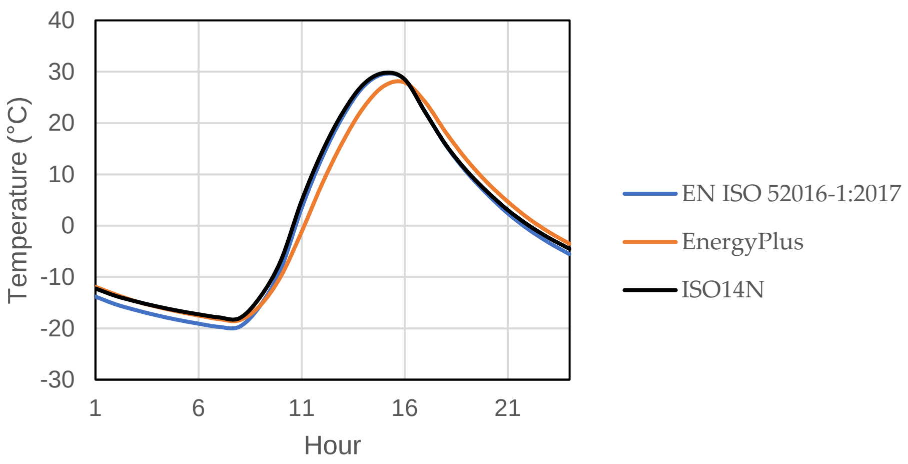

Figure S1. Hourly operative temperature on January the 4th for case 600FF (lightweight building, free floating simulation).

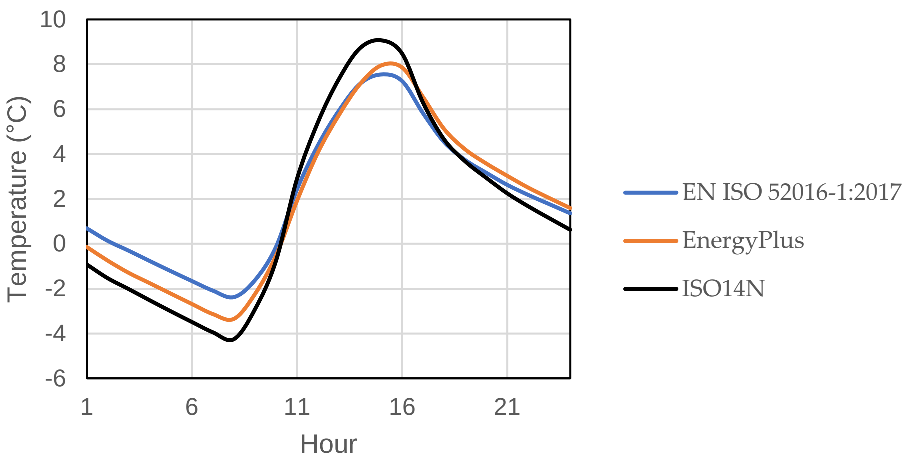

Figure S2. Hourly operative temperature on January the 4th for case 900FF (heavyweight building, free floating simulation).

The reliability of ISO14N model can be evaluated quantitatively by computing statistic indices such as the root mean squared error, RMSE, the mean bias error, MBE, and the coefficient of variation of the root mean squared error, Cv(RMSE) [5]. These are defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(\theta_{\mathrm{ISO14N},i} - \theta_{\mathrm{ref},i}\right)^2}{N}}$$

$$MBE = \frac{\sum_{i=1}^{N}(\theta_{\mathrm{ISO14N},i} - \theta_{\mathrm{ref},i})}{\sum_{i=1}^{N}\theta_{\mathrm{ref},i}} \cdot 100$$

$$Cv(RMSE) = \frac{RMSE}{\theta_{\mathrm{ref,m}}}$$

where $\theta_{\mathrm{ISO14N},i}$ is the simulated temperature from ISO14N at time step i, $\theta_{\mathrm{ref},i}$ is the corresponding operative temperature simulated by the reference software (EN ISO 52016-1:2017 or EnergyPlus), $\theta_{\mathrm{ref,m}}$ is the mean operative temperature simulated by the reference software over the considered time period, and N is the overall number of time steps in the considered time period. Indices *MBE* and *Cv*(*RMSE*) can also be compared with the recommendations set in ASHRAE Guideline 14-2014 [6]. The calculated indices over the year (8760 time steps) and the relevant ASHRAE quality thresholds are reported in Tables S1–S2.

Table S1. Evaluation of ISO14N model prediction capabilities on hourly basis with respect to reference software for case 600FF (lightweight, free-floating).

	RMSE	*MBE*	*Cv(RMSE)*
EN ISO 52016-1:2017	0.61°C	0.2%	2.4%
EnergyPlus	3.08°C	5.5%	12.5%
Threshold	-	±10%	30%

Table S2. Evaluation of ISO14N model prediction capabilities on hourly basis with respect to reference software for case 900FF (heavyweight, free-floating).

	RMSE	*MBE*	*Cv(RMSE)*
EN ISO 52016-1:2017	0.88°C	0.2%	3.4%
EnergyPlus	2.06°C	4.8%	8.3%
Threshold	-	±10%	30%

In terms of monthly calculations, the agreement of ISO14N predictions to EN ISO 52016-1:2017 predictions is excellent in both lightweight and heavyweight cases (Figures S3–S4 and Tables S3–S4).

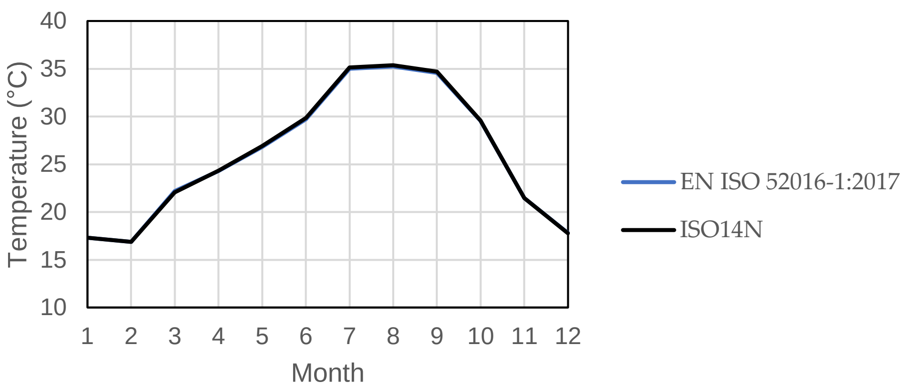

Figure S3. Average monthly operative temperature for case 600FF (lightweight building, free floating simulation).

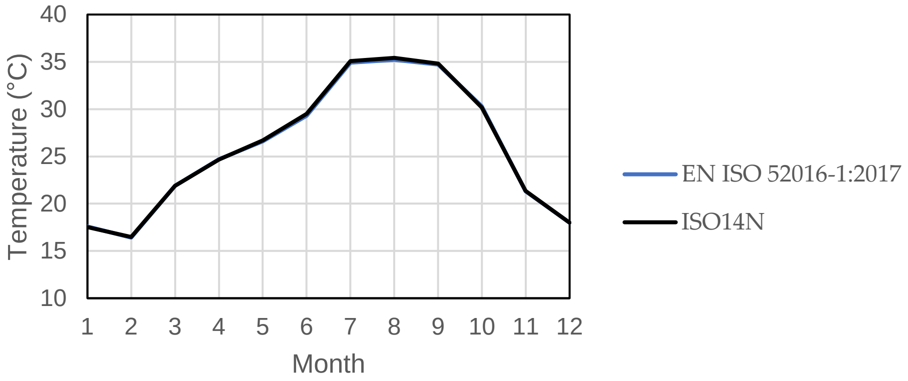

Figure S4. Average monthly operative temperature for case 900FF (heavyweight building, free floating simulation).

Table S3. Evaluation of ISO14N model prediction capabilities on monthly basis with respect to reference software for case 600FF (lightweight, free-floating).

	RMSE	*MBE*	*Cv(RMSE)*
EN ISO 52016-1:2017	0.09°C	0.2%	0.3%
Threshold	-	±5%	15%

Table S4. Evaluation of ISO14N model prediction capabilities on monthly basis with respect to reference software for case 900FF (heavyweight, free-floating).

	RMSE	*MBE*	*Cv(RMSE)*
EN ISO 52016-1:2017	0.12°C	0.2%	0.4%
Threshold	-	±5%	15%

3. Cases with Continuous or Intermittent Thermostat Control Strategy

3.1. Operative Temperature

From a qualitative observation (Figures S5–S8), the simplified ISO14N model seems to slightly overestimate the average operative temperature, except in the coldest months of the year in the heavyweight case when it considerably underestimates it. In particular, months 2 and 12 in case 940 (intermittent operation) are the most critical in terms of prediction agreement to the standard. However, the quantitative evaluation reported in Tables S5–S6 shows that the simplified is characterized by an overall acceptable level of prediction capability.

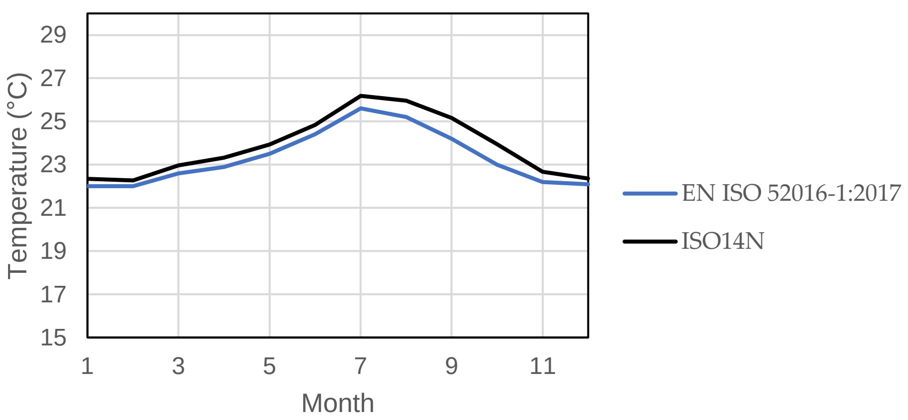

Figure S5. Average monthly operative temperature for case 600 (lightweight building, continuous thermostat control strategy).

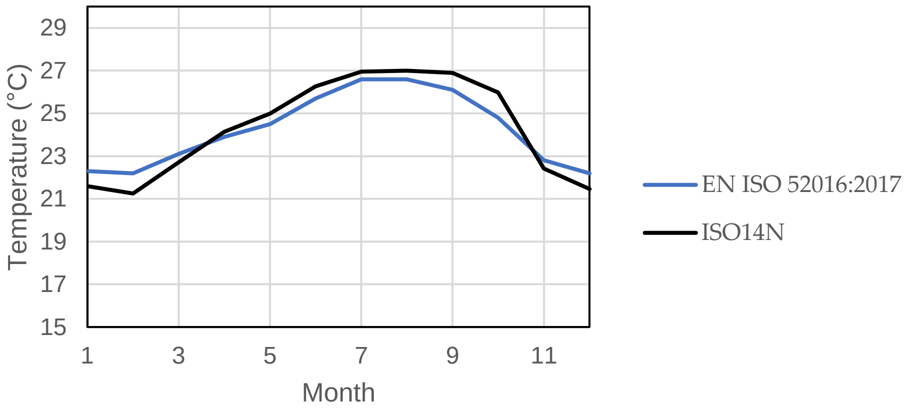

Figure S6. Average monthly operative temperature for case 900 (heavyweight building, continuous thermostat control strategy).

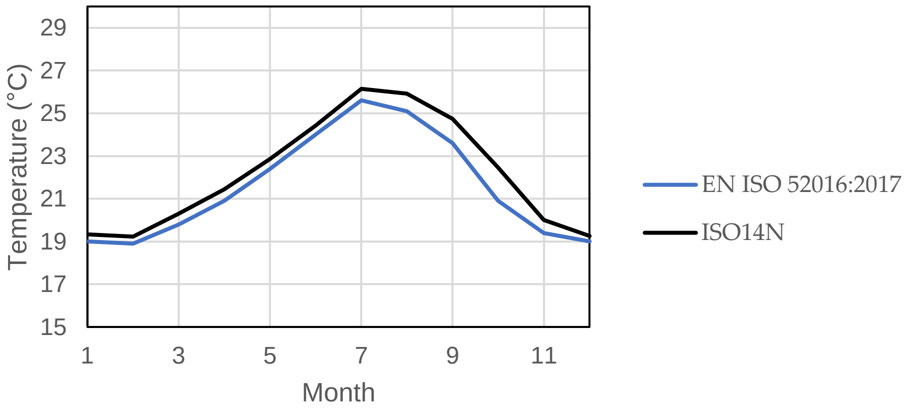

Figure S7. Average monthly operative temperature for case 640 (lightweight building, intermittent thermostat control strategy with night-time set-back for heating).

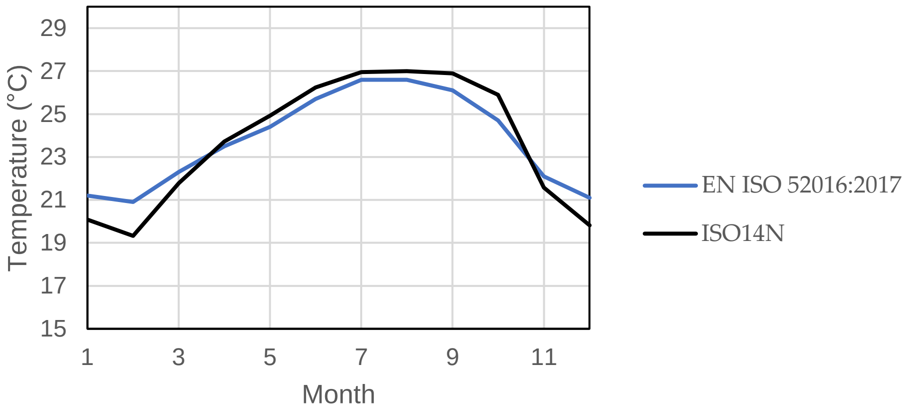

Figure S8. Average monthly operative temperature for case 940 (heavyweight building, intermittent thermostat control strategy with night-time set-back for heating).

Table S5. Evaluation of ISO14N model prediction capabilities on monthly basis with respect to EN ISO 52016-1:2017 for case 600 and 640 (lightweight, continuous and intermittent operation).

	RMSE	*MBE*	*Cv(RMSE)*
600	0.57°C	2.2%	2.5%
640	0.73°C	2.9%	3.4%
Threshold	-	±5%	15%

Table S6. Evaluation of ISO14N model prediction capabilities on monthly basis with respect to EN ISO 52016-1:2017 for case 900 and 940 (heavyweight, continuous and intermittent operation).

	RMSE	*MBE*	*Cv(RMSE)*
900	0.73°C	-1.1%	3.2%
940	0.86°C	-0.3%	3.6%
Threshold	-	±5%	15%

3.2. Heating and Cooling Loads

Hourly heating and cooling loads are compared on a reference day of January, as prescribed by EN ISO 52016-1:2017. The graphs show that the more simplified the distributions of the masses, the more the building seems sensitive to outdoor variations, as a result of underestimating the time constant. For this reason, the differences are particularly evident in the heavyweight cases, 900 and 940, and in the comparison of EnergyPlus simulations with the two standard-based methods. This confirms the findings of Ballarini et al. [5], who compared the results of EN ISO 52016-1:2017, EN ISO 13790:2008 and EnergyPlus.

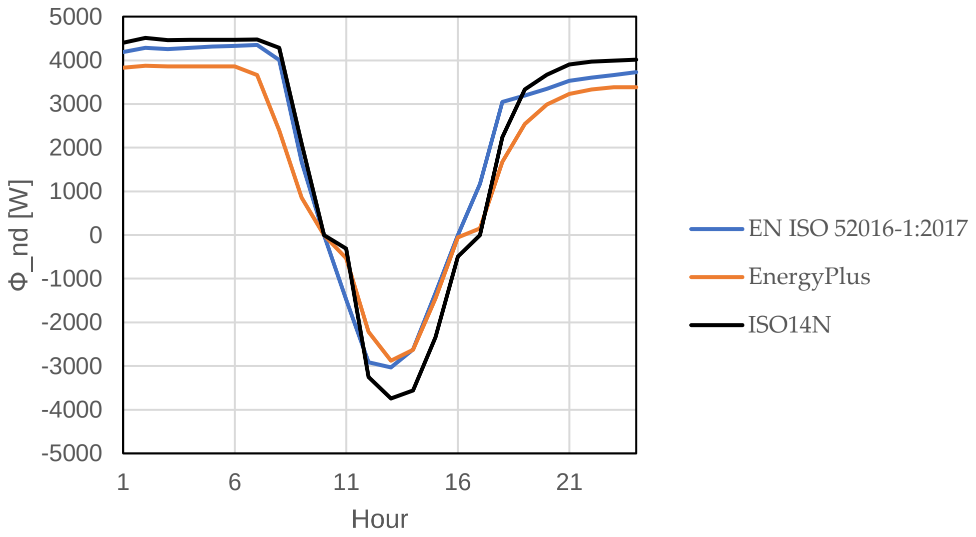

Figure S9. Hourly sensible heating (+) and cooling (−) load on January the 4th for case 600 (lightweight building, continuous thermostat control strategy).

Table S7. Peak heating and cooling load for case 600 (lightweight building, continuous thermostat control strategy).

	EN ISO 52016-1	**EnergyPlus**	**ISO14N**
Heating peak load (W)	4351	3875	4513
Cooling peak load (W)	6363	6086	7360

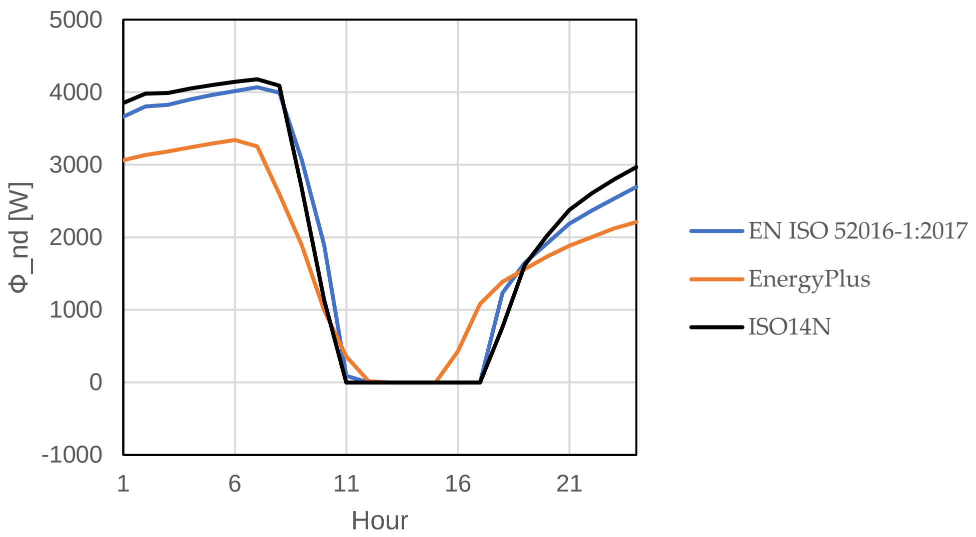

Figure S10. Hourly sensible heating (+) and cooling (−) load on January the 4th for case 900 (heavyweight building, continuous thermostat control strategy).

Table S8. Peak heating and cooling load for case 900 (heavyweight building, continuous thermostat control strategy).

	EN ISO 52016-1	EnergyPlus	ISO14N
Heating peak load (W)	4067	3341	4933
Cooling peak load (W)	4043	2950	4741

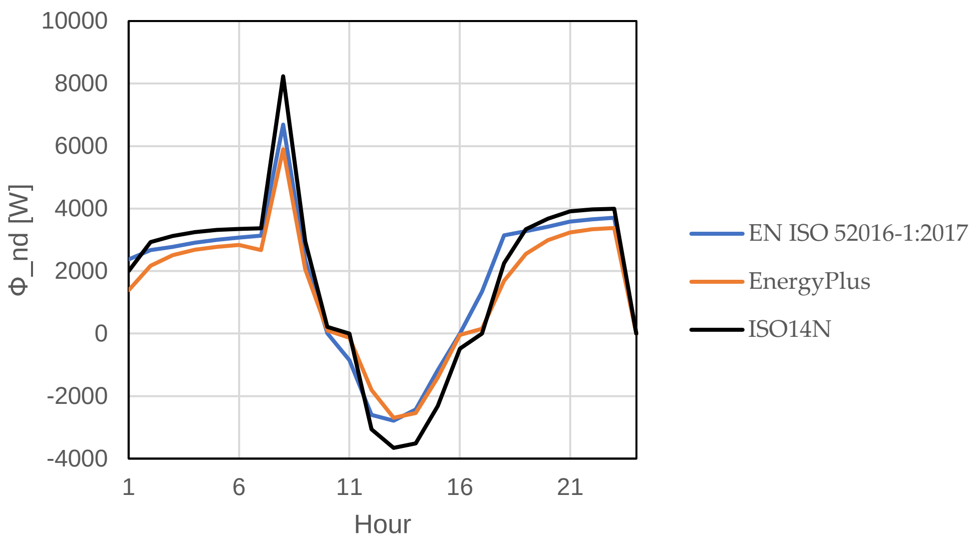

Figure S11. Hourly sensible heating (+) and cooling (−) load on January the 4th for case 640 (lightweight building, intermittent thermostat control strategy with night-time set-back for heating).

Table S9. Peak heating and cooling load for case 640 (lightweight building, intermittent thermostat control strategy with night-time set-back for heating).

	EN ISO 52016-1	EnergyPlus	ISO14N
Heating peak load (W)	6690	6826	8230
Cooling peak load (W)	6233	5989	7281

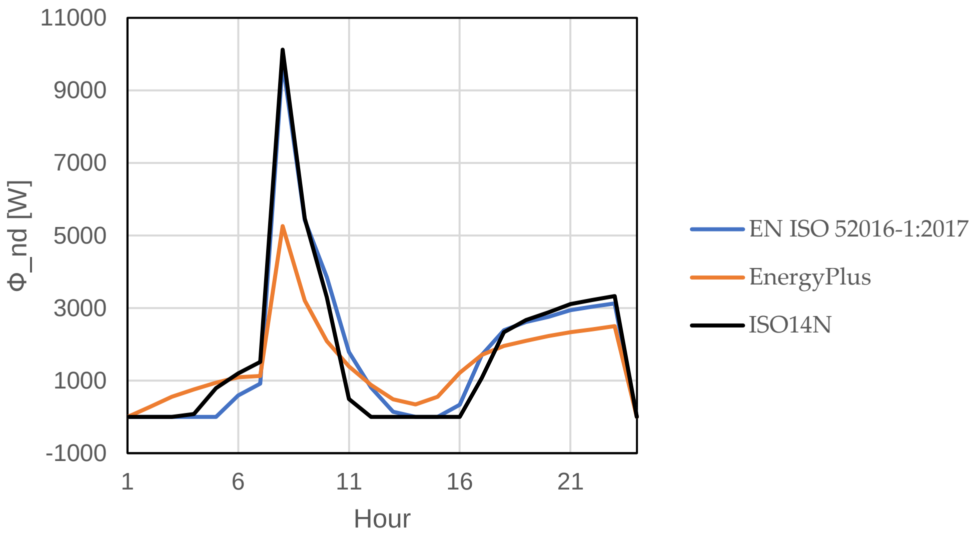

Figure S12. Hourly sensible heating (+) and cooling (−) load on January the 4th for case 940 (heavyweight building, intermittent thermostat control strategy with night-time set-back for heating).

Table S10. Peak heating and cooling load for case 940 (heavyweight building, intermittent thermostat control strategy with night-time set-back for heating).

	EN ISO 52016-1	EnergyPlus	ISO14N
Heating peak load (W)	9793	5583	10123
Cooling peak load (W)	4047	2950	4741

3.3. Sensible Energy Needs for Heating and Cooling

Monthly sensible energy needs obtained with ISO14N model have similar trends as EN ISO 52016-1:2017 results. As already observed in operative temperature and heating/cooling load comparisons, the simplified model tends to overestimate the heating needs, particularly in the coldest months, and to overestimate the cooling needs, but the trends are comparable to those obtained with the original standard. In light of the approximations introduced in ISO14N model, its prediction capabilities is considered comparable to those of EN ISO 52016-1:2017 standard for the tested cases.

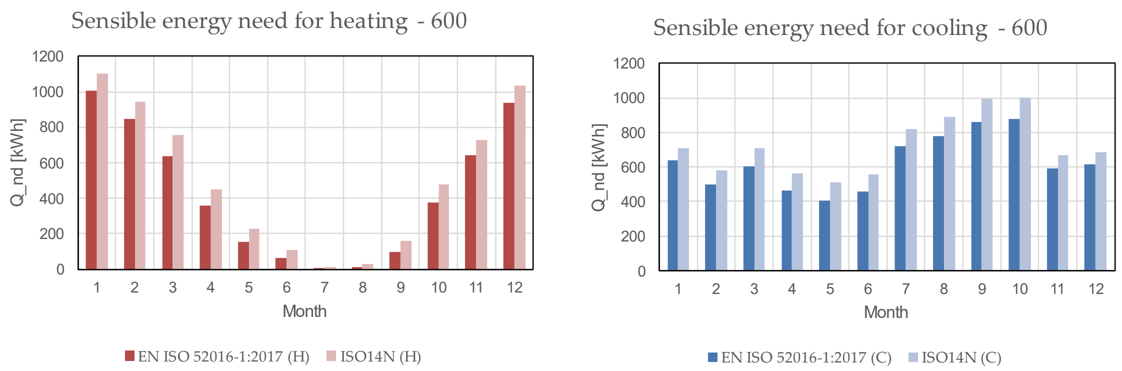

Figure S13. Monthly sensible energy needs for heating (solid lines) and cooling (dashed lines) for case 600 (lightweight building, continuous thermostat control strategy).

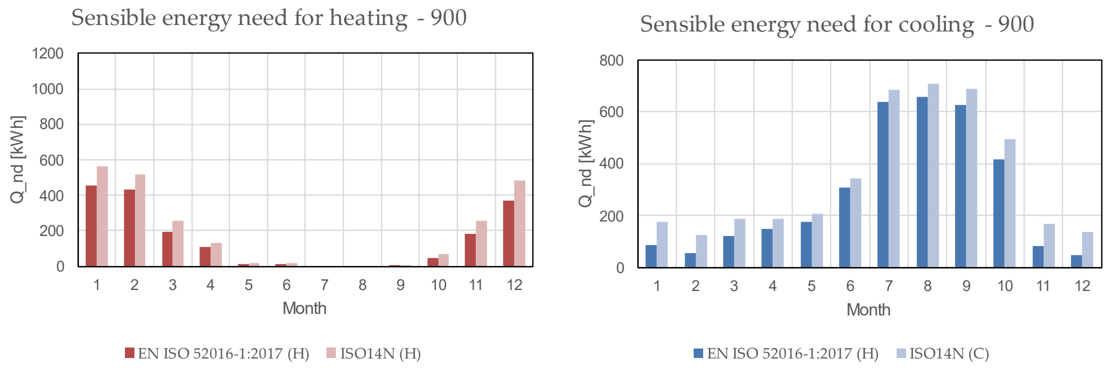

Figure S14. Monthly sensible energy needs for heating (solid lines) and cooling (dashed lines) for case 900 (heavyweight building, continuous thermostat control strategy).

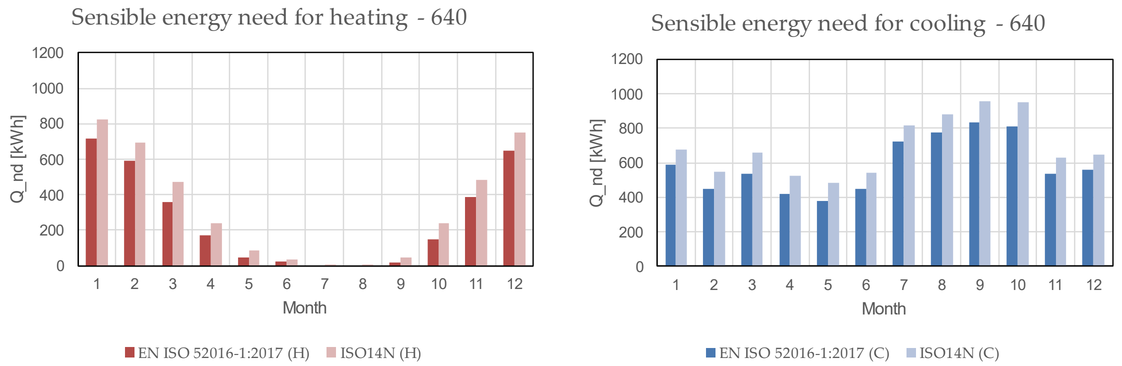

Figure S15. Monthly sensible energy needs for heating (solid lines) and cooling (dashed lines) for case 640 (lightweight building, intermittent thermostat control with night-time set-back for heating).

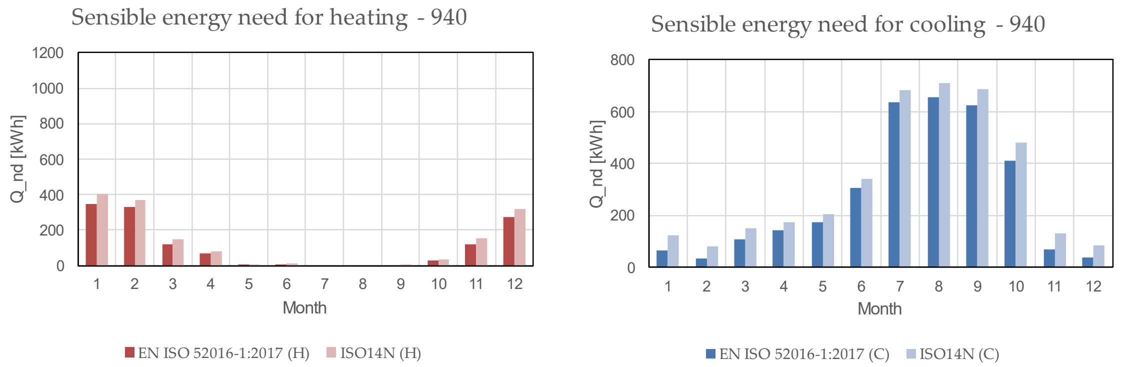

Figure S16. Monthly sensible energy needs for heating (solid lines) and cooling (dashed lines) for case 940 (heavyweight building, intermittent thermostat control with night-time set-back for heating).

References

1. CEN/TC 89 EN ISO 52016-1:2017 Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures; European Committee for Standardization, CEN: Brussels, Belgium, 2017;
2. Lundström, L.; Akander, J.; Zambrano, J. Development of a space heating model suitable for the automated model generation of existing multifamily buildings—a case study in Nordic climate. Energies **2019**, 12, doi:10.3390/en12030485.

3. EPB Center — Documents — EPB Center | EPB Standards Available online: https://epb.center/documents/demo-en-iso-52016-1/ (accessed on Nov 12, 2020).
4. EnergyPlus Testing and Validation Available online: https://energyplus.net/testing (accessed on Dec 12, 2020).
5. Ballarini, I.; Costantino, A.; Fabrizio, E.; Corrado, V. The Dynamic Model of EN ISO 52016-1 for the Energy Assessment of Buildings Compared to Simplified and Detailed Simulation Methods. In Proceedings of the Building Simulation 2019; Rome, Italy, 2019; pp. 3847–3854.
6. American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE ASHRAE Guideline 14-2014 -- Measurement of Energy, Demand, and Water Savings; ASHRAE Inc.: Tullie Circle, NE, Atlanta, GA, USA, 2014;