Fictitious cooling/heating: from free-floating thermal discomfort to energy needs, different approaches toward labelling free-running buildings

Original

Fictitious cooling/heating: from free-floating thermal discomfort to energy needs, different approaches toward labelling free-running buildings / Chiesa, G. - In: JOURNAL OF PHYSICS. CONFERENCE SERIES. - ISSN 1742-6588. - ELETTRONICO. - 2600:9(2023). [10.1088/1742-6596/2600/9/092011]

Publisher:

IOP

Published

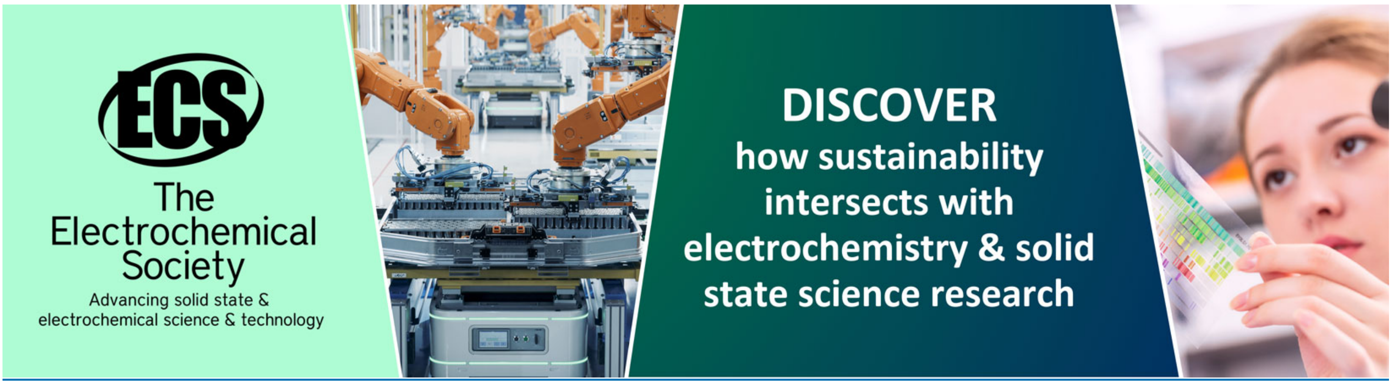
DOI:10.1088/1742-6596/2600/9/092011

Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Fictitious cooling/heating: from free-floating thermal discomfort to energy needs, different approaches toward labelling free-running buildings

To cite this article: G Chiesa 2023 *J. Phys.: Conf. Ser.* **2600** 092011



CISBAT 2023 IOP Publishing
Journal of Physics: Conference Series **2600** (2023) 092011 doi:10.1088/1742-6596/2600/9/092011

Fictitious cooling/heating: from free-floating thermal discomfort to energy needs, different approaches toward labelling free-running buildings

G Chiesa[1]

[1] Politecnico di Torino, Department of Architecture and Design, Turin, Italy
giacomo.chiesa@polito.it

Abstract. Free-running (FR) buildings and technologies, e.g. ventilative cooling, are generally not considered and valorised in energy labelling schemes. The paper analyses three approaches to transfer discomfort conditions into comparable fictitious energy needs in order to evaluate FR building performances. The first approach adds a virtual mechanical system to the FR building; the second approach includes in the previous the effect of controlled free-running potentialities, e.g. ventilative cooling in summer, while in the third one, fictitious energy needs are calculated by coupling a double simulation flow, i.e. FR vs mechanical-treated building, assuming energy needs from the latter when the first is exceeding assumed discomfort thresholds. The paper underlines a very high correlation between energy needs and parallel FR indoor temperatures. Initial results show how the first approach loses the FR potential, while the second and the third can valorise FR technologies. The choice of different discomfort thresholds can be used to orient the impact of FR technologies from very to slightly positive.

1. Introduction and objectives

A free-running building (FR) can be defined as a building without a mechanical cooling and/or heating system or a building in which systems are turned off. Traditional and historic buildings in several European contexts are free-running for at least one of the seasons, e.g. the cooling season in northern Europe, or even both, like in typical southern European buildings. In Italy alone, 8.6% of buildings do not have a heating system installed [1]. Considering the summer season, the penetration of air conditioners in European residential buildings is also limited, reaching only about 8%, as underlined in the literature [2]. Nevertheless, the free-running mode is not sufficiently considered and valorised in EPCs (Energy Performance Certifications). For example, it is generally not possible to label a building that does not have a heating system. However, the energy certification of a free-running building may be released in some national/regional applications by considering a standard virtual heating system with low efficiency, i.e. a mean statistical COP [3], see also D.Lgs 192/2005 for the Italian domain. Similarly, it was underlined, e.g. by IEA EBC Annex 62, how the positive effect of ventilative cooling and other low-energy strategies is rarely included in standard rating conditions [4]. The study of methodologies able to define a performance definition of free-running building behaviours in terms of virtual energy is hence essential to valorise the untapped potential of free-running technologies, especially in the cooling season [5]. Including free-running potentials in building, modelling requires significant efforts to overcome several challenges, i.e. the definition of specific key performance indicators (KPIs), the development of methodologies for their verifications and the assessment of standardised methods including the adoption of dynamic models, recognised as essential for correctly define natural and passive behaviours – see for example[6] .

This paper focuses on the above-mentioned challenge, introducing three potential methodologies to define fictitious energy needs of free-running buildings and verifying their meaning on a sample set of simulations performed for the summer season via a dynamic energy simulation tool. The work is conducted during the project E-DYCE (Energy flexible DYnamic building Certification), co-funded by the EU under the topic "Next-generation of Energy Performance Assessment and Certification".

2. The proposed methodologies

The paper compares three approaches to define fictitious energy needs in free-running buildings by simulating via EnergyPlus a sample residential unit in a southern European climate. The approaches are:

i. adding a "virtual" heating/cooling system without including free-running strategies. For this paper the useful energy is considered, even if a typical COP/EER may be assumed in line with some current standards;
ii. adding a "virtual" heating/cooling system considering the positive effect of traditional free-running building strategies, e.g. ventilative cooling (summer), e.g.[7];
iii. calculating the fictitious heating/cooling needs based on local discomfort conditions. The latter approach expands the fictitious cooling vision reported in Annex D of the ISO TR EN 52018-2:2017 to define a methodology to valorise traditional free-running buildings.

This last new approach simulates a building twice under the same weather conditions: firstly, in free-running mode considering adaptive thermal comfort conditions, and secondly, in mechanical mode to retrieve hourly energy needs. When discomfort is envisaged in the first simulation, e.g. hours below/above Cat.II lower$^-$/upper$^+$ comfort limit (EN 16798-1), a fictitious heating/cooling value for the same hour, is extracted from the second parallel simulation. The fictitious energy need can be for example linearly weighted [0-100%] in the interval between Cat.II(0%) and Cat.III(100%), and fully assumed for below/above Cat.III. To analyse the impact of these thresholds (0-100%), four combinations of adaptive thermal comfort categories are assumed: Cat.II(0%)→Cat.III(100%); Cat.I→II; Cat.0→II; Cat.III(below 0%, above 100%). The significance of fictitious heating/cooling is discussed by showing a.) sample demo results for the 3-proposed approaches – Section 3 – and b.) the existing correlations between energy needs and free-running temperatures when the same building is run in the mechanical and free-running modes under the same boundary conditions. For this study, a sample south-oriented parallelepiped building with a shape of 10 x 10 x 3.5m (monozonal model), a window-to-wall ratio of 30% for all orientations, and a wall U-value of 1.8 W/m^{2}K is assumed. The same is simulated under the typical meteorological Mediterranean climate of Rome, assuming the EnergyPlus TMY3 file.

Results underline how the first method badly considers traditional buildings working in free-running, the second in which free-running is considered by valorising some passive strategies on a set-point vision, and the third in which the free-running is fully considered, including adaptive thermal comfort models. However, future studies are needed to tune the correlation between discomfort and fictitious energy needs, potentially including a user-centred study on perceptions and cooling activation behaviours and an analysis of the prediction of the passive strategies' potential.

3. Sample demo results for the 3-proposed methodologies

EnergyPlus simulation results for the 3-approaches are reported in Table 1 considering the solely sensible cooling, and in Table 2 for the total cooling, considering adding a dehumidification control with a 70% RH threshold (Cat. III), in line with split unit control solutions. In order to simplify this testing phase, the useful energy calculated by the simple HVAC mode of EnergyPlus is assumed, without applying final energy conversion, considering that for all methodologies the same EER/COP would be considered for this analysis. A cooling set point of 26°C is assumed, while ventilated cases use a scheduled air-exchanges per hour (ACH) of 5 with a control logic assuming a difference in temperature between inside and outside higher than 2K, in line with literature suggestions [8]. Results include the cooling energy needs for method 1, method 2, and method 3 (fictitious cooling). At the same time, four different adaptive thermal comfort boundary strategies are adopted to define the fictitious cooling activation. Additionally, the fictitious cooling in the case in which the free-running model is run without ventilation is also retrieved to verify the meaning of the third proposed methodology. Results show a high difference between method 1 and method 2, confirming that method 2 is able to consider the positive effect of natural cooling solutions, i.e. the ventilative cooling heat gain dissipation. Differently, the fictitious cooling shows an intermediate behaviour with respect to the two previous methodologies, suggesting that this third approach is able to define a virtual energy need for free-running discomfort. However, it is precautionary with respect to methodology 2, including a slight benefit with respect to methodology 1 that does not consider the positive impact of bioclimatic strategies and body abilities to adapt in free-running conditions. Among the different threshold approaches, the ones referring to very low upper classes (I$^+$-II$^+$ and 0-II$^+$) are limiting the impact of the free-running potential, especially in May and September, while the intermediate case (II$^+$-III$^+$) shows results more aligned with methodology 2, taking full advantage from the adaptive comfort in hotter months. Finally, the case that uses Cat. III$^+$ as a single threshold is overestimating the free-running potential, especially in the hotter months and when dehumidification is assumed, being accepting higher discomfort boundaries. It can be mentioned that the fictitious cooling evaluation, with respect to methodology 2, is not able to consider the positive effect of intermittent cooling activations (or hybrid cooling solutions) in modulating the heat gains acting on thermal masses requiring further studies. Focussing on the meaning of methodology III, a correlation is evident between original cooling energy needs and fictitious cooling ones in the case without ventilation. This result is deepened in Section 4. Specific sensitivity studies are under development to confirm these preliminary outcomes under different boundary conditions.

Table 1. Sensible cooling (useful energy [kWh]) needs by the three described methodologies.

↓[kWh]	May	Jun	Jul	Aug	Sep	May-Sep
Qc	-1567	-2090	-2602	-2447	-1738	-10444
Qc-AHC	-375	-933	-1818	-1682	-855	-5662
Fictitious II$^+$-III$^+$	-659	-1077	-1729	-1533	-800	-5662
Fictitious I$^+$-II$^+$	-819	-1323	-1898	-1701	-960	-6702
Fictitious 0-II$^+$	-969	-1496	-2071	-1883	-1105	-7524
Fictitious III$^+$	-551	-954	-1651	-1432	-705	-5293
Fictitious II$^+$-III$^+$ no vent.	-1567	-2090	-2602	-2447	-1737	-10442

Table 2. Total cooling (useful energy [kWh]) energy needs by the three described methodologies.

↓[kWh]	May	Jun	Jul	Aug	Sep	May-Sep
Qc	-1905	-2585	-3142	-3049	-2207	-12888
Qc-AHC	-445	-1214	-2204	-2241	-1119	-7223
Fictitious II$^+$-III$^+$	-739	-1245	-1983	-1796	-924	-6687
Fictitious I$^+$-II$^+$	-925	-1541	-2195	-2011	-1119	-7791
Fictitious 0-II$^+$	-1106	-1760	-2419	-2256	-1305	-8846
Fictitious III$^+$	-616	-1101	-1887	-1670	-810	-6085
Fictitious II$^+$-III$^+$ no vent.	-1903	-2585	-3142	-3049	-2205	-12884

4. Discussing the correlations between free-running discomfort and mechanical energy needs

This Section discusses the significance of the fictitious cooling/heating KPI. This discussion bases on a progressive series of considerations. Firstly, it is possible to remind that: a.) in mechanically conditioned buildings, it is possible to identify a direct correlation between environmental conditions and space energy needs; and that b.) in free-running buildings a parallel correlation exists between environmental conditions and space thermal comfort/discomforts indoor conditions, studying the building free-floating temperature. These correlations are well-known, such as underlined by the definition of climate-energy correlated indices, such as the heating-degree days (HDD) and the cooling-degree days (CDD). These indices are recognised by Member States' (MS) energy regulations. For example, the Italian standard heating season for each Municipality is a function of the local climate zone, based on the defined HDD values – UNI/TS 11300-1 and DPR 74/2013 –, while the use of HDD and CDD values in defining the operational heating and cooling seasons is also underlined [9]. Additionally, the linear connection between energy losses and indoor-outdoor temperature differences is also included in steady-state energy transmission expressions. Considering free-running buildings and passive solutions, the correlation between degree-day indices and free-running building conditions is also demonstrated in several studies – see for example [8,10]–, while the same is also adopted to support the definition of the local climatic potential of free-running technologies, considering both space heating and space cooling, e.g. [11,12]. Figure 1 shows an example for each of the two mentioned correlations a.) and b.) obtained by simulating the same sample building respectively with and without systems. The analysis is performed on the mentioned sample demo building.

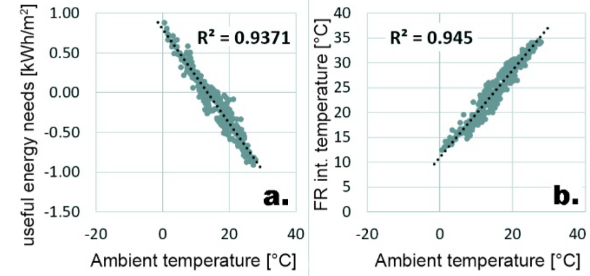


Figure 1. Daily aggregated correlations between (a) energy needs and environmental temperatures – mechanical mode – and (b) FR building indoor temperatures vs external ones.

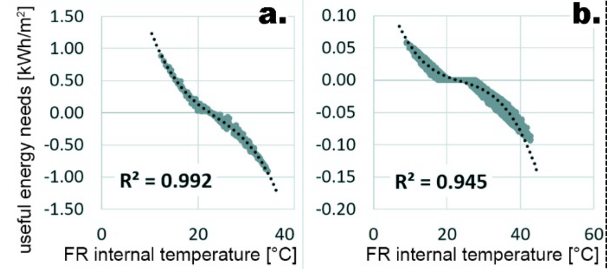


Figure 2. Correlations between energy needs (mechanical mode) and free-running internal temperatures considering different time-aggregation intervals: (a) daily and (b) hourly.

Secondly, it is analysed that, assuming the two previous conditions, a third potential correlation may be identified between building energy needs in the mechanical mode and internal temperatures – expressing the thermal discomfort – of the same building working in the free-running mode under the same weather conditions. Figure 2 confirms this third correlation by plotting the internal temperature of the free-running simulated mode as a function of the energy needs of the same building simulated in the mechanical mode. The correlation is analysed by using statistical indicators showing a very high R^2 for both linear (0.98 – not plotted) and polynomial (0.99) regressions in average daily results. Considering hourly aggregations, results are confirmed in both cases reaching respectively a R^2 of 0.87 for the linear regression and 0.94 for the polynomial one. The graph underlines that it is possible to correlate energy needs in the mechanical mode with free-running temperatures, especially at daily aggregated data resolutions, which is still a detailed result even with respect to other energy indicators, such as the energy signature, which is generally weekly or monthly aggregated. Focussing on hourly-resolution results, the main discrepancies are due to a high number of hours in which no cooling or heating is needed. However, the majority of these hours are also those in which the free-running mode model is retrieving indoor temperatures in the comfort heating and cooling ranges between 20 and 26°C.

Thirdly, an analysis of the robustness of the proposed approach is performed by adding variations to the boundary conditions, considering in particular: i.) add ventilative cooling (for the sole free-running mode, and in both cases - indoor/outdoor temperature control activation, scheduled air-exchanges per hour (ACH) set to 5); ii.) change the U-value (from 1.8 to 0.2 W/m2); iii.) change the climate data, by simulating the same sample building in a different location (from Rome to Torre Pellice, a semi-mountain city in the Piedmont region in which are located the E-DYCE Italian demo cases); iv.) change the occupancy (both free-running and mechanical modes) and the heating and cooling (mechanical mode only) scheduling profile (from a residential case 24h/7d to an office building 8-18/Mon-Fri).

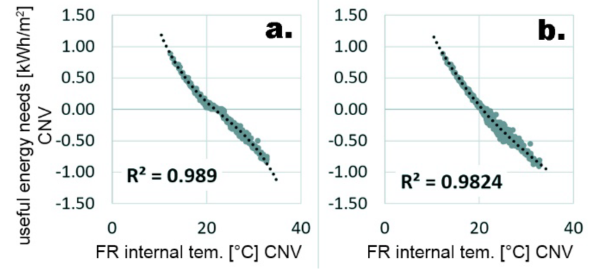


Figure 3. Retrieved correlations for variation i.), considering added ventilation for both free-running and mechanical modes (a) and for the sole free-running mode (b). Results are based on daily aggregated data.

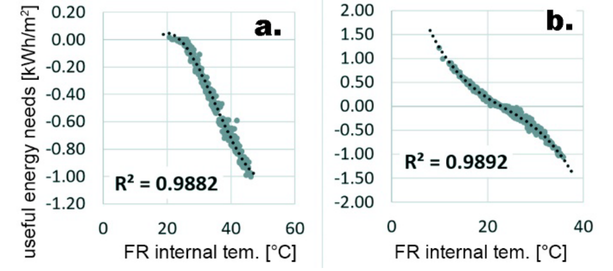


Figure 4. Daily correlations between simulated FR internal temperatures and energy needs in the mechanical mode. (a) reduced U-value (0.2 W/m2K) – variation ii.) – and (b) assuming Torre Pellice typical weather– variation iii.).

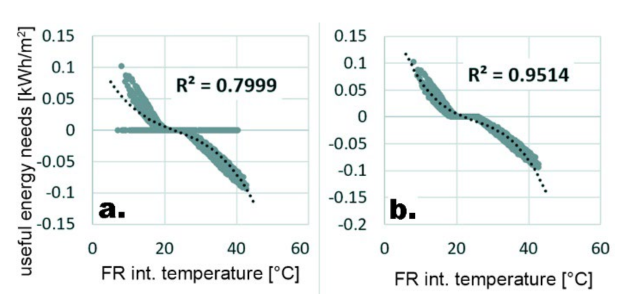


Figure 5. Correlations between free-running internal temperatures and energy needs, office scheduled cases, considering only occupied hours (hourly aggregation) (a), and occupied hours without turning off and on periods (8- 17) (b).

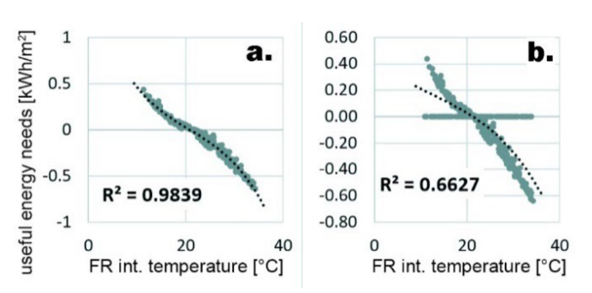


Figure 6. Same as Fig. 6 but for daily-aggregated values: (a) only occupied day, (b) all days.

Results of variation i.) are shown in Figure 3 considering the left ventilation in both modes and on the right graph ventilation added to the sole free-running case. In both cases, very high correlations are retrieved between the mechanical and free-running evaluation variables – respectively energy needs and internal temperatures. Graphs in Figure 4 report the obtained correlations for variation cases ii.) and iii.). For both analyses, a high correlation is still retrieved showing the robustness of the approach. Considering hourly aggregated correlations, a slight increase in standard deviations is shown reaching 0.95 for variation i.) and 0.86 for variation ii.), although results are still very significant. Focussing on variation iv.), the effect of schedule changes is shown in Figure 5. In hourly correlations, a valuable correlation is retrieved when filtered on the equipment schedule including early morning and evening system turning on and off periods ($R^2 = 0.79$), while by filtering results for the office occupation interval, i.e. from 8:00 to 17:00, the correlation becomes very high ($R^2 = 0.95$). Differently, if all yearly hours are considered (8760 h), the correlation level rises down to a R^2 of 0.44 due to the high number of hours in which the system is off, while temperature variations arrive in the free-running mode. Nevertheless, comfort evaluations are expected to be performed during occupation periods, underlining the coherence of the proposed filtering approach. Similar results are obtained for daily-aggregated data – see Figure 6 – assuming all hours, but of the sole working days. In this latter case, the correlation is also very high ($R^2 = 0.98$), while in the case in which also weekends are assumed, the correlation is significant, but limited to an R^2 of 0.66.

5. Conclusions

The paper underlined how to evaluate, with translated energy virtual values, the free-running-potential exploitation and eventually include these aspects in EPC, it is important to define proper methodologies to: i. focus on the comfort/discomfort domain; ii. transpose discomfort condition into fictitious "virtual" energy needs to compare FR-building behaviours with mechanically-driven ones. Focussing on the FR virtual energy for EPC applications, three methodologies are introduced and tested in this paper including general considerations, although, the approach is under testing in different demo cases to compare results and suggest a more-consolidated E-DYCE approach for FR performance evaluation. This paper shows how the mentioned approaches underline the possibility on the one side of translating discomfort conditions into fictitious energy needs to allow FR building comparison with mechanically treated spaces, and on the other side to define local FR potential to evaluate its exploitation performance. It is possible hence to remind the importance of expanding the EPC current approach, including comfort-connected KPIs, allowing to evaluate of standard building performances on a wide base. Furthermore, the three methods are open to different potential interpretations, including the choice of boundary translation limits in the hourly and daily evaluation of the fictitious needs, balancing the "virtual" cooling needs as a fraction of the simulated active building with respect to FR discomfort intensities. A sensitivity analysis will be conducted during the final project phases considering simulated and monitored data. Hence, the assumption of both the maximal limit value (e.g. overpassing of upper comfort limits, e.g. the ones of Class III in adaptive comfort model – EN 16798-1:2019) and especially the initial threshold value (over which overheating is assumed) represents itself an indicator, potentially defining a comfort quality label. It is important to remind that this approach is not intending to valorise energy poverty but underlines the need to correctly evaluate and valorise traditional and low-energy solutions exploiting local free-running potentials rebalancing the importance of local climatic culture and the correct application of bioclimatic design principles, which are often excluded by labelling approaches. In all cases, when an FR building is not able to guarantee the required comfort temperature category, this inadequacy needs to be underlined not only in the design document (see EN 16798-1:2019, item 6.2.2), but also in the proposed FR certification, e.g. by adopting one or more of the FR KPIs suggested in the E-DYCE project. In conclusion, it may be stated that the analysed fictitious cooling approach can be easily expanded to other comfort domains and variables, supporting the possibility of comparing and eventually labelling free-running modes on the base of comfort performance issues.

Acknowledgement

This project has received funding from the EU Horizon 2020 research and innovation programme under GA No. 893945 (E-DYCE). This paper is partially expanding the contents of Deliverable D3.3.

References

[1] ISTAT 2013 15° CENSIMENTO DELLA POPOLAZIONE E DELLE ABITAZIONI 2011
[2] Santamouris M 2019 *Cooling energy solutions for buildings and cities* (New Jersey: World Scientific)
[3] Certificazione-Energetica.it 2017 Certificazione-energetica-per-immobili-senza-impianto-di-riscaldamento-come-fare? *Certificazione-Energetica.it*
[4] Holzer P and Psomas T 2018 *Ventilative cooling sourcebook, Annex 62* (Aalborg: Un. Press)
[5] Plesner C and Pomianowski M Z 2021 Ventilative Cooling in Standards, Legislation and Compliance tools *Innovations in Ventilative Cooling* (Cham: SPRINGER) p 26pp
[6] Heiselberg P 2018 *IEA EBC Annex 62 - Ventilative Cooling Design Guide* (Aalborg: Un. Press)
[7] Grosso M 2017 *Il raffrescamento passivo degli edifici* (Sant'Arcangelo di Romagna: Maggioli)
[8] Chiesa G, Heiselberg P K and Kolokotroni M 2021 *Innovations in Ventilative Cooling* (Cham: Springer International Publishing)
[9] CISBE 2006 *Degree-days: Theory and application* (London: CIBSE)
[10] Cook J 1989 *Passive Cooling* (Cambridge: MIT press)
[11] Chiesa G and Grosso M 2015 *Energy and Buildings* **107** 376–91
[12] Artmann N, Manz H and Heiselberg P 2007 *Applied Energy* **84** 187–201